

Biochar Production for Project Reporting Protocol

GHG Emission Reduction Accounting

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1.0 Introduction

This protocol provides accounting, reporting, and monitoring procedures to determine greenhouse gas (GHG) reductions associated with biochar production and use as defined herein.

Biochar is produced through the Thermochemical Conversion of biomass in the absence of oxygen. Under this protocol, potential Feedstocks are defined as woody biomass and include forestry and agriculture residues, along with a limited set of other biomass-based materials approved for use under the International Biochar Initiative's (IBI) Biochar Standards (2013) and as defined herein. In the absence of Thermochemical Conversion, these Feedstocks would otherwise be combusted or decompose, releasing carbon dioxide (if combustion or decomposition under aerobic conditions occurs) or methane (if decomposition occurs under anaerobic conditions).

Thermochemical Conversion physically and chemically transforms the carbon in raw biomass into a more recalcitrant form, which can be applied to soil for long-term sequestration. A large portion of the Fixed Carbon in Biochar, as measured using the testing methods identified herein, is sequestered for a time period well in excess of 100 years. By transforming the biomass carbon to a highly stable form that resists degradation, and ensuring that it remains in this form, emissions from the decomposition or combustion of feedstocks are significantly reduced.

In addition to this sequestration, Thermochemical Conversion can also generate bio-oil and syngas. These fuels may be used as renewable energy and thus reduces anthropogenic greenhouse gas (GHG) emissions by offsetting fossil fuel use.

This protocol quantifies these GHG emission reductions and sequestration benefits that result from the implementation of Biochar projects.

2.0 **Project**

Under this protocol Biochar feedstock is restricted to woody biomass that is generated from forestry, agriculture, urban landscaping, and related industries. Biochar is a solid material obtained from the carbonisation of biomass. Alternatives to biochar production include open burning, decay and decomposition in the field, or landfill. Eligible biomass residues shall reduce wildfire fuel loads and include, but are not limited to forestry and agricultural residues including:

- Forest slash (non-merchantable) remains from forest management activities including timber harvesting or forest thinning and fuel hazard reduction. These include small trees, brush, tree tops, and branches.
- Defensible space clearing residues (brush, tree branches and trunks, clippings).
- Orchard and vineyard removals and prunings.
- Field straws and stalks.
- Urban prunings/cuttings residues.

Applicable Biochar uses include as a grow media and/or soil amendment. The production of the Biochar may also result in the production of heat, electricity, oil and/or gas.

Sources of GHG emissions from a biochar production project are shown in Table 1.

2.1 **Project Definition**

For this protocol, the GHG reduction project involves the creation of Biochar, where otherwise under baseline business as usual conditions, the various feedstock would be left to decay, be combusted via open pile burning, transported to a local landfill for aerobic decay or used for bioenergy production.

The project developer must provide information defining the project operations, including:

- Location where the biochar feedstock is generated.
- Operation for which the biochar feedstock is a byproduct, i.e. how is the biochar feedstock generated.
- Generation (rate and timing) of the biochar feedstock.
- Composition of the biochar feedstock.
- Historical, current, and anticipated future, disposal practice for the biochar feedstock in the absence of the proposed biochar feedstock to energy project.
- Biochar feedstock processing operations prior to transport, such as conveyors, grinders, and loaders.
- Biochar feedstock transportation method.
- Location of biochar production facility.
- Generation rate of energy from biochar feedstock.
- End-uses of the Biochar
- Permitting status of the biochar production facility.

- Documentation of environmental assessments required as part of the biochar feedstock generating activities. These might include the National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), California Forest Practices Rules and Regulations, and/or Timber Harvest Plans.

This information must be provided in Attachment A, included as an attachment to the protocol. Attachment A must be completed, submitted, and approved prior to project commencement.

2.2 Project Proponent

The Project Proponent must demonstrate uncontested and exclusive claim to the ownership of the GHG benefits derived from the project activities. The Project Proponent must have documentation to address and resolve all potential claims to GHG benefits by the Feedstock producer, Biochar producer, retailer and end-user. Any transfer of carbon rights must be clearly documented.

2.3 Methane and Nitrous Oxide Global Warming Potential Characterization Factors

Methane (CH₄) has a global warming potential characterization factor of 25 tons of CO_{2e} per ton of methane.

Nitrous oxide (N₂O) has a global warming potential characterization factor of 298 tons CO_{2e} per ton N₂O.

3.0 Eligibility

Projects must meet the following requirements to be eligible for GHG offset credits under this protocol.

3.1 Biochar production from Qualified Operations

The biomass waste material used for energy recovery must be characterized as:

- “Feedstock” – The material undergoing thermochemical conversion processes to create Biochar. Feedstock materials for Biochar consist of Biogenic materials, but may also contain Diluents and no more than 2% by dry weight of Contaminants. (International Biochar Initiative 2013)
- “Excess waste” – The material must be an excess waste byproduct that, in the absence of the project, would be left to decay, be combusted via open pile burning, transported to a local landfill for aerobic decay or used for bioenergy production.
- “Sustainable” – The material must be a byproduct of operations which:
 - Protect or enhance long-term productivity of the site by maintaining or improving soil productivity, water quality, wildlife habitat, and biodiversity.
 - Meet all local, state, and federal environmental regulations, including National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), California Forest Practices Rules and Regulations, and/or Timber Harvest Plans.

3.2 Additionality

Project GHG emission reductions must be “additional” to what would have otherwise occurred.

It must be demonstrated that the existing, baseline business as usual disposal practice of the biochar feedstocks at the beginning date of the project is through either:

- Open burning in the vicinity of the production site. It must be demonstrated that this disposal practice is a legally allowable method under the local Air District and the State and that an open pile burn permit has been or could be obtained.
- Decay and decomposition in the vicinity of the production site, with no commercial value derived from the end-product.
- Landfilled.

In the alternative, the baseline assumption will be that the biomass was being used for the production of bioenergy, as outlined under the default baseline calculations in this protocol.

The project developer must demonstrate there are no alternative uses for the biochar feedstock, other than those listed above. It must not be currently economical within the local market to utilize or sell the biochar feedstock as a product or process feedstock. This requires providing

documentation of previous historical disposal practices, current disposal practices in the absence of the proposed project, and future planned/anticipated disposal practices.

3.3 Biochar Production and Product Use

The Biochar production facility must acquire all applicable permits for operation. Biochar products must be handled and used in a manner that complies with all local, state and federal regulations. Project proponents are expected to present relevant documentation to indicate that regulatory requirements have been met upon request from governing authorities.

Co and end-products, including but not limited to Biochar, bio oil, biogas, heat and electricity, must be documented and exempt from claims on other projects to ensure accuracy in GHG accounting and quantification of other mitigation activities.

3.4 Location

This protocol is applicable to biochar production project operations that are located within the state of California.

3.5 Project Start Date

Projects are eligible which begin after the date of approval of the protocol, or after January 1, 2007 for qualifying early action projects, and after the necessary project initiation forms have been completed and approved (including Attachment A).

4.0 Assessment Boundary

The biochar feedstock project boundary is defined to include all GHG emissions from operations that are the result of the biochar production project. The physical boundary of the biochar feedstock for energy project is shown in Figure 1. GHG emissions must be accounted for operations, as detailed in Table 2.0, including:

4.1 Baseline, Business as Usual

- Open biomass burning. Includes quantification of CO₂, CH₄, and N₂O.
- Decay and decomposition of biomass disposal in field. Includes quantification of CH₄ and N₂O.
- Landfill. Includes quantification of CH₄.

In the alternative, the baseline assumption will be that the biomass was being used for the production of bioenergy, as outlined under the default baseline calculations in this protocol.

- Alternative heat and electricity production as well as fossil fuel (oil and gas) use. Includes quantification of CO₂, CH₄, and N₂O.

4.2 Biochar Production Project

- Biomass Fossil fuel fired engines used to facilitate transport of biochar feedstock from the site of generation to the biochar production facility. Includes quantification of CO₂, CH₄ and N₂O.
- Biochar feedstock usage at the biochar production facility. For biomass combustion boilers, quantification of CO₂ is not required as it is considered biogenic. The quantification of CH₄ and N₂O is required for the combustor. Includes quantification of CH₄ and N₂O.
- Fossil fuel fired engines used at biochar production facility for operation of auxiliary equipment, such as conveyors, loaders, processing equipment and blending equipment that would not have been used otherwise in the absence of the project. Includes quantification of CO₂, CH₄ and N₂O emissions.
- Bio-oil and syngas eventual use either on- or off-site. Quantification of the CO₂ is not required as it is considered biogenic. The quantification of CH₄ and N₂O is required for the combustor. Includes quantification of CH₄ and N₂O.
- Sequestration of carbon in biochar that is secured for a period of greater than 100 years. Includes quantification of CO₂.
- Processing of non-biogenic feedstock elements that may be present in the feedstock. Includes quantification of CO₂, CH₄ and N₂O emissions.

5.0 Calculation Methods

5.1 Project Emissions

Emissions under the project condition (in tonnes CO₂e) are determined using the following equation:

$$PE_{PROJ} = PE_{TR,y} + PE_{P,y} + PE_{Py,y} + PE_{E,y} + PE_{PNB,y} + PE_{B,y} + PE_{OP,y} + PE_{GP,y} + PE_{OU,y} + PE_{GU,y} - C_{BS,y} \quad (1)$$

Where:

PE_{PROJ} = the sum of the project emissions in year y (t CO₂e)

$PE_{TR,y}$ = emissions due to the transportation T of Feedstocks in year y (t CO₂e).

$PE_{P,y}$ = emissions associated with the processing P and drying of Feedstock in year y (t CO₂e)

$PE_{Py,y}$ = emissions due to the combustion of auxiliary fuel for the purpose of Thermochemical Conversion Py of Feedstock in year y (t CO₂e)

$PE_{E,y}$ = auxiliary emissions from the net consumption of electricity E under the project condition in year y (t CO₂e)

$PE_{PNB,y}$ = emissions due to the Thermochemical Conversion P of non-biogenic NB Feedstock materials in year y (t CO₂e)

$PE_{B,y}$ = auxiliary emissions due to the blending and processing of Biochar B in year y (t CO₂e)

$PE_{OP,y}$ = auxiliary emissions due to the processing of bio-oil OP in year y (t CO₂e)

$PE_{GP,y}$ = auxiliary emissions due to the processing of syngas GP in year y (t CO₂e)

$PE_{OU,y}$ = auxiliary emissions due to the use of bio-oil OU in year y (t CO₂e)

$PE_{GU,y}$ = auxiliary emissions due to the use of syngas GU in the year y (t CO₂e)

$C_{BS,y}$ = carbon sequestration S associated with the appropriate end use and/or in-situ application of Biochar B in year y (t CO₂e)

5.1.1 Feedstock Transportation

In cases where the Biomass Residues are not generated directly at the project site, Project Proponents shall determine CO₂ emissions resulting from transportation of the Biomass Residues to the project plant using the latest version of the tool “Project and Leakage emissions from road transportation of freight” from the Clean Development Mechanism. $PE_{TR,m}$ in the tool corresponds to the parameter $PE_{TR,y}$ in this protocol and the monitoring period m is one year.

5.1.2 Processing and Drying Feedstock

The emissions associated with the processing and drying of Feedstock are calculated as follows:

$$PE_{P,y} = \sum (Fuel_{P,i,y} \times EF_{Fuel_{CO_2}}); \sum (Fuel_{P,i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{P,i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (2)$$

Where:

$PE_{P,y}$ = project emissions associated with the processing P and drying of Feedstock in year y (tCO₂e)

$Fuel_{P,i,y}$ = the volume of each type of fossil fuel used for drying in year y (L, m³ or other)

EF_{CO_2} = the CO₂ emission factor for each type of fossil fuel (t CO₂/L, m³ or other)

EF_{CH_4} = the CH₄ emission factor for each type of fossil fuel (t CH₄/L, m³ or other)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

EF_{N_2O} = the N₂O emission factor for each type of fossil fuel (t N₂O/L, m³ or other)

GWP_{N_2O} = Global Warming Potential of N₂O (t CO₂e/t N₂O)

5.1.3 Auxiliary Fuel Combustion

The emissions due to the combustion of auxiliary fuel for the purpose of Thermochemical Conversion of Feedstock are calculated as follows:

$$PE_{PY,y} = \sum (Fuel_{PY,i,y} \times EF_{Fuel_{CO_2}}); \sum (Fuel_{PY,i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{PY,i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (3)$$

Where:

$PE_{PY,y}$ = project emissions due to the combustion of auxiliary fuel for the purpose of Thermochemical Conversion Py in year y of Feedstock (tCO₂e)

$Fuel_{PY,i,y}$ = the volume of each type of Thermochemical Conversion Py fuel (fuel type i) used in year y (L, m³ or other)

EF_{CO_2} = the CO₂ emission factor for each type of fossil fuel (t CO₂/L, m³ or other)

EF_{CH_4} = the CH₄ emission factor for each type of fossil fuel (t CH₄/L, m³ or other)

GWP_{CH_4} = Global Warming Potential of CH_4 (t CO_2e /t CH_4)

EF_{N_2O} = the N_2O emission factor for each type of fossil fuel (t N_2O /L, m^3 or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.1.4 Electricity Consumption

The emissions due to the consumption of electricity in the project condition are calculated as follows:

$$PE_{E,y} = E_{G,y} \times EF_{Grid} \quad (4)$$

Where:

$PE_{E,y}$ = project emissions due to the consumption of electricity E in the project condition (t CO_2e) in year y

$E_{G,y}$ = the quantity of grid G electricity consumed in the project condition in year y (MWh)

EF_{Grid} = the regional electricity grid emission factor (t CO_2e /MWh)

5.1.5 Fuel for Processing Bio-Oil

The auxiliary emissions due to the processing of bio-oil are calculated as follows:

$$PE_{OP,y} = \sum (Fuel_{OP\ i,y} \times EF_{Fuel_{CO_2}}); \sum (Fuel_{OP\ i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{OP\ i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (5)$$

Where:

$PE_{OP,y}$ = project emissions due to the processing of bio-oil OP in year y (t CO_2e)

$Fuel_{OP\ i,y}$ = the volume of each type of (oil processing OP) fuel i used in year y (L, m^3 or other)

EF_{CO_2} = the CO_2 emission factor for each type of fossil fuel (t CO_2 /L, m^3 or other)

EF_{CH_4} = the CH_4 emission factor for each type of fossil fuel (t CH_4 /L, m^3 or other)

GWP_{CH_4} = Global Warming Potential of CH_4 (t CO_2e /t CH_4)

EF_{N_2O} = the N_2O emission factor for each type of fossil fuel (t N_2O /L, m^3 or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.1.6 Fuel for Processing Syngas

The auxiliary emissions due to the processing of syngas are calculated as follows:

$$PE_{GP,y} = \sum (Fuel_{GP\ i,y} \times EF_{Fuel_{CO_2}}); \sum (Fuel_{GP\ i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{GP\ i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (6)$$

Where:

$PE_{GP,y}$ = project emissions due to the processing of syngas GP (tCO₂e) in year y

$Fuel_{GP\ i,y}$ = the volume of each type of syngas GP fuel i used in year y (L, m³ or other)

EF_{CO_2} = the CO₂ emission factor for each type of fossil fuel (t CO₂/L, m³ or other)

EF_{CH_4} = the CH₄ emission factor for each type of fossil fuel (t CH₄/L, m³ or other)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

EF_{N_2O} = the N₂O emission factor for each type of fossil fuel (t N₂O/L, m³ or other)

GWP_{N_2O} = Global Warming Potential of N₂O (t CO₂e/t N₂O)

5.1.7 Fuel for Processing and/or Blending Biochar

The auxiliary emissions due to the processing and/or blending of Biochar are calculated as follows:

$$PE_{BL,y} = \sum (Fuel_{BL\ i,y} \times EF_{Fuel_{CO_2}}); \sum (Fuel_{BL\ i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{BL\ i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (7)$$

Where:

$PE_{BL,y}$ = project emissions due to the processing and/or blending of Biochar BI (tCO₂e) in year y

$Fuel_{BL\ i,y}$ = the volume of each type of fuel i used in year y (L, m³ or other)

EF_{CO_2} = the CO₂ emission factor for each type of fossil fuel (t CO₂/L, m³ or other)

EF_{CH_4} = the CH₄ emission factor for each type of fossil fuel (t CH₄/L, m³ or other)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

EF_{N_2O} = the N₂O emission factor for each type of fossil fuel (t N₂O/L, m³ or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.1.8 Bio-Oil Use

The auxiliary emissions due to the use of bio-oil are calculated as follows:

$$PE_{OU,y} = \sum (Fuel_{OU\ i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{OU\ i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (8)$$

Where:

$PE_{OU,y}$ = project emissions due to the use of bio-oil OU in year y (t CO_2e)

$Fuel_{OU\ i,y}$ = the volume of each type of fuel i used in year y (L, m^3 or other)

EF_{CH_4} = the CH_4 emission factor for bio-oil used (t CH_4 /L, m^3 or other)

GWP_{CH_4} = Global Warming Potential of CH_4 (t CO_2e /t CH_4)

EF_{N_2O} = the N_2O emission factor for bio-oil used (t N_2O /L, m^3 or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.1.9 Syngas Use

The auxiliary emissions due to the use of syngas are calculated as follows:

$$PE_{GU,y} = \sum (Fuel_{GU\ i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{GU\ i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (9)$$

Where:

$PE_{GU,y}$ = project emissions due to the use of syngas GU in year y (t CO_2e)

$Fuel_{GU\ i,y}$ = the volume of each type of fuel i used in year y (L, m^3 or other)

EF_{CH_4} = the CH_4 emission factor for syngas used (t CH_4 /L, m^3 or other)

GWP_{CH_4} = Global Warming Potential of CH_4 (t CO_2e /t CH_4)

EF_{N_2O} = the N_2O emission factor for syngas used (t N_2O /L, m^3 or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.1.10 Biochar in Situ

The sequestration associated with the appropriate end use and/or application of Biochar in situ is calculated following procedures and measurements outlined in the “Standard Test Method for Estimating Biochar Carbon Stability” by the International Biochar Initiative (2013), which is Appendix A in this Protocol. The stability of carbon in Biochar is calculated first by determining the ratio of hydrogen to organic carbon within the Biochar, and then through comparing that ratio to a series of 100 plus year stability values that were determined through extensive consultation with soil scientists, Biochar scientists and Biochar producers as part of the development of the Biochar carbon stability documentation. The organic carbon ratio and the 100 plus year stability value are then inserted into the following formula to calculate the mass of sequestered carbon in Biochar. (Appendix A)

$$C_{BS,j,y} = BC_{w,y} \times C_{org,j,y} \times BC_{+100} \times [(100 - M_{j,y})/100] \times \frac{44}{12} \times 0.95 \quad (10)$$

Where:

$C_{BS,y}$ = Stable 100-year sequestration *BS* associated with the appropriate end use and/or in-situ application of Biochar type *w* (which was produced with a consistent Feedstock type under uniform production parameters, following the *IBI Biochar Standards* (International Biochar Initiative 2013)) in year *y* (t CO₂e)

$BC_{j,y}$ = Mass of Biochar type *w* in year *y* (metric tonnes)

$C_{org,j,y}$ = Organic Carbon ratio as a percentage of Biochar *j* in year *y*

BC_{+100} = percentage of Biochar carbon that is stable for at least 100 years in situ

$M_{j,y}$ = moisture content % of Biochar type *w* in year *y*

44/12 = molar ratio of carbon dioxide to carbon

0.95 = correction factor used to account for any possible positive priming effect of adding Biochar to soil. (International Biochar Initiative 2013a).]

These measurements and calculations must be repeated for each subsequent year of production or after any Material Change in Feedstock or process activity as outlined in the “Standard Test Method for Estimating Biochar Carbon Stability” document (International Biochar Initiative 2013a).

5.2 Baseline Emissions

Baseline quantification in this methodology is projection based, using projections of reductions or removals in the project to estimate the baseline emissions that would have occurred in the absence of the project. Emissions under the baseline condition are determined using the following equations:

5.2.1 Default Baseline

(Feedstock would have been used only for bioenergy production)

$$BE_{BASE} = BE_{B,y} \quad (11)$$

Where:

BE_{Base} = the sum of the baseline emissions in year y

$BE_{B,y}$ = emissions due to the combustion of Feedstock for bioenergy B production in year y

OR, with appropriate evidence:

5.2.2 Alternative Baseline

$$BE_{BASE} = BE_{A,y} + BE_{An,y} + BE_{C,y} + BE_{E,y} + BE_{O,y} + BE_{G,y} + BE_{H,y} \quad (12)$$

Where:

BE_{BASE} = the sum of the baseline emissions in year y

$BE_{A,y}$ = emissions due to the aerobic decomposition A of Feedstock in year y

$BE_{An,y}$ = emissions due to the anaerobic decomposition An of Feedstock in an SWDS in year y

$BE_{C,y}$ = emissions due to the combustion C of Feedstock without bioenergy production in year y

$BE_{E,y}$ = auxiliary emissions due to the use of electricity E in year y

$BE_{O,y}$ = auxiliary emissions due to the use of fossil oil O in year y

$BE_{G,y}$ = auxiliary emissions due to the use of fossil gas G in year y

$BE_{H,y}$ = auxiliary emissions due to the use of heat H in year y

Step 1: Identify the baseline condition

Project Proponents shall use the steps outlined in Section 4.0 of this document to determine the Baseline condition *i* for each Feedstock.

Table 1: Baseline Conditions

Baseline condition <i>i</i>	Parameter (FS _i)
Bioenergy production (default)	FS _B
Aerobic decomposition	FS _A
Anaerobic decomposition in a SWDS	FS _{An}
Combustion without bioenergy production	FS _C

Every stream of Feedstock that is processed into Biochar is assumed to be diverted from bioenergy production under the default calculations (Equation 12: $BE_{BASE} = BE_{B,y}$), unless otherwise justified by the procedure for determining the Baseline Scenario. Alternative Feedstock diversions may include those for aerobic decomposition, anaerobic decomposition in a Solid Waste Disposal Site (SWDS), or combustion without energy capture, and are addressed using the alternative calculations.

Step 2: Identify the Feedstock Composition

The composition of Feedstock from Biomass Residues should be assessed. The amount of Feedstock type *w* prevented from baseline disposal *i* is calculated using sampling as follows:

$$FS_{i,j,y} = \sum_i FS_{i,y} \times \frac{\sum_{n=1}^Z p_{n,j,y}}{Z} \quad (13)$$

Where:

FS_{i,j,y} = the amount of Feedstock type *w* prevented from baseline disposal *i* in year *y* (t)

FS_{i,y} = total amount of Feedstock prevented from baseline disposal *i* in year *y* (t)

P_{n,j,y} = weight fraction of the Feedstock type *W* in the sample *n* collected during year *y* (t)

Z = number of samples collected during year *y*

Equation (14) determines the fraction of each individual Feedstock type used for one discreet Biochar production event (same Feedstock blend ratios and same production parameters). The mass of each Feedstock type (e.g. straw) is calculated by identifying the fraction it represents in the total mass of incoming Feedstock. Thus, if a Feedstock is a 60:35:5 blend of straw, wood chips, and non-biogenic material (as identified by following Feedstock determination and

sampling procedures outlined in the *IBI Biochar Standards* (2013)), and the total volume of incoming Feedstock diverted from landfill disposal is 240 tonnes for year 1, the calculation is: 240t * 0.6 for straw, 240t * 0.35 for wood chips, and 240t * 0.05 for non-biogenic materials, resulting in 144, 84, and 12 tonnes for straw, wood chips and non-biogenic Feedstocks, respectively. This same procedure may be used to identify the total volume of each Feedstock fraction, for each disposal type, including non-biogenic materials. These $FS_{i,j,y}$ values will be used in subsequent calculations to determine the total emission reduction.

5.2.3 Bioenergy Production (Default Project)

The emissions due to the combustion of Feedstock for producing bioenergy (heat and/or electricity) are calculated as follows:

$$BE_{B,y} = \sum_i FS_{Bj,y} \times EF_{CH_4,i} \times GWP_{CH_4}; \sum_i FS_{Bj,y} \times EF_{N_2O,i} \times GWP_{N_2O} \quad (14)$$

Where:

$BE_{B,y}$ = Baseline emissions due to the combustion of Feedstock for bioenergy B (tCO₂e) production in year y

$FS_{B,w,y}$ = the amount of Feedstock type w prevented from baseline condition bioenergy production B in year y (t)

$EF_{CH_4,i}$ = the CH₄ emission factor for the Feedstock type w prevented from the baseline condition i (t CH₄/t)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

$EF_{N_2O,i}$ = the N₂O emission factor for the Feedstock type w prevented from the baseline condition i (t N₂O/t)

GWP_{N_2O} = Global Warming Potential of N₂O (t CO₂e/t N₂O)

5.2.4 Aerobic Decomposition (Alternative)

The emissions due to the aerobic decomposition of Feedstock are calculated as follows:

$$BE_{A,y} = \sum (FS_{A,j,y} \times EF_{ACH_4,y} \times GWP_{CH_4}) ; (FS_{A,j,y} \times EF_{AN_2O,y} \times GWP_{N_2O}) \quad (15)$$

Where:

$BE_{A,y}$ = Baseline emissions due to the aerobic decomposition A of Feedstock in year y

$FS_{A,j,y}$ = the fraction of Feedstock type w diverted from aerobic decomposition A in year y (t)
 $EF_{ACH_4,y}$ = the emission factor for methane CH_4 per tonne of waste diverted from aerobic decomposition A valid in year y (t CH_4 /t)

GWP_{CH_4} = Global Warming Potential of CH_4 (t CO_2e /t CH_4)

$EF_{AN_2O,y}$ = the emission factor for nitrous oxide N_2O per tonne of waste diverted from aerobic decomposition A , valid in year y (t N_2O /t)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.2.5 Anaerobic Decomposition in a SWDS (Alternative)

The emissions due to the anaerobic decomposition of Feedstock in an SWDS are calculated as follows:

$$BE_{An,y} = \varphi \times (1 - f_y) \times GWP_{CH_4} \times (1 - OX) \times \frac{16}{12} \times F \times DOC_{f,y} \times MCF_y \times \sum_{y=1}^{10} \sum_i FS_{an,j,y} \times [e^{-k_j \cdot (y-1)} \times (1 - e^{-k_j})] \times DOC_j \quad (16)$$

Where:

$BE_{An,y}$ = Baseline emissions due to the anaerobic decomposition An of Feedstock in an SWDS in year y

φ = Model correction factor to account for model uncertainties for year y

f_y = the recovered methane at the landfill in year y (%)

GWP_{CH_4} = the Global Warming Potential of methane CH_4 (t CO_2e /t CH_4)

OX = the oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil or other material covering the waste)

$16/12$ = Ratio of molecular weights of Methane (16) to Carbon (12)

F = the fraction of methane in the SWDS gas (%)

$DOC_{f,y}$ = the fraction f of degradable organic carbon that decomposes under the specific conditions occurring in the SWDS for year y

MCF_y = Methane conversion factor for year y

$FS_{an,j,y}$ = the amount of Feedstock type w prevented from baseline condition anaerobic decomposition AN in an SWDS in year y (t)

DOC_j = the degradable organic carbon in the Feedstock type w

k_j = the decay rate for the Feedstock type w (l/yr)

5.2.6 Combustion (Alternative)

The emissions due to the combustion of Feedstock without bioenergy production are calculated as follows:

$$BE_{C,y} = \sum_i FS_{C,j,y} \times EF_{CH_4,i} \times GWP_{CH_4}; \sum_i FS_{C,j,y} \times EF_{N_2O,i} \times GWP_{N_2O} \quad (17)$$

Where:

$BE_{C,y}$ = baseline emissions due to the combustion C of Feedstock without bioenergy production (tCO₂e) in year y

$FS_{C,j,y}$ = the amount of Feedstock type w prevented from baseline condition combustion C in year y (t)

$EF_{CH_4,i}$ = the CH_4 emission factor for combustion of the Feedstock type w baseline condition (pathways i) (t CH₄/t)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

$EF_{N_2O,i}$ = the N₂O emission factor for combustion of the Feedstock type w (t N₂O/t)

GWP_{N_2O} = Global Warming Potential of N₂O (t CO₂e/t N₂O)

5.2.7 Electricity Production

The emissions due to the production of electricity that would have been required to compensate for the renewable electricity produced in the project condition are calculated as follows:

$$BE_{E,y} = E_{R,y} \times EF_{Grid} \quad (18)$$

Where:

$BE_{E,y}$ = baseline emissions due to the production of electricity E that would have been required to compensate for the renewable electricity produced in the project condition (tCO₂e) in year y

$E_{R,y}$ = the net quantity of renewable electricity R generated in the project condition and used off-site in year y (MWh)

EF_{Grid} = the regional electricity *grid* emission factor (t CO₂e/MWh)

These baseline emissions $BE_{E,y}$, however, cannot be accounted for in the following scenarios:

1. The default baseline bioenergy production has been indicated for the project. If any portion of the Feedstock used by the project would have been used for bioenergy production in the baseline, the Project Proponent cannot account for $BE_{E,y}$
2. If the project is generating, claiming and selling Renewable Energy Certificates (RECs) or other environmental credits, the Project Proponent cannot account for $BE_{E,y}$. If RECs have been issued, the Project Proponent shall either not include this emission source or provide evidence that the RECs have not been used and have been cancelled from the environmental credit program.

5.2.9 Oil

The emissions due to the use of fossil oil that would have been required to compensate for the bio-oil produced in the project condition are calculated as follows:

$$BE_{O,y} = \sum (Fuel_{i,y} \times EF_{Fuel_{CO_2}}) + \sum (Fuel_{i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}) + \sum (Fuel_{i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O})$$

$$Fuel_i = O_y \times \%_i$$
(19)

Where:

$BE_{O,y}$ = baseline emissions due to the use of fossil oil O that would have been required to compensate for the bio-oil produced in the project condition (tCO₂e) in year y

$Fuel_{i,y}$ = the volume of each type of liquid fuel i to generate an equivalent amount of bio-oil on an energy basis in year y (L, m³ or other)

O_y = the volume of bio-oil produced in the project condition in year y (L, m³ or other)

$\%_i$ = the percentage of each type of fuel offset (%)

EF_{CO_2} = the CO₂ emission factor for each type of fuel (t CO₂/L, m³ or other)

EF_{CH_4} = the CH₄ emission factor for each type of fuel (t CH₄/L, m³ or other)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

EF_{N_2O} = the N_2O emission factor for each type of fuel (t N_2O /L, m^3 or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.2.10 Gas

The emissions due to the use of fossil gas that would have been required to compensate for the syngas produced in the project condition are calculated as follows:

$$BE_{G,y} = \sum (Fuel_{i,y} \times EF_{Fuel_{CO_2}}) + \sum (Fuel_{i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}) + \sum (Fuel_{i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (20)$$

$$Fuel_i = G_y \times \%_i$$

Where:

$BE_{G,y}$ = baseline emissions due to the use of fossil gas G that would have been required to compensate for the syngas produced in the project condition (t CO_2e) in year y

$Fuel_{i,y}$ = the volume of each type of gaseous fossil fuel i to generate an equivalent amount of syngas on an energy basis in year y (L, m^3 or other)

G_y = the volume of syngas produced in the project condition in year y (L, m^3 or other)

$\%_i$ = the percentage of each type of fuel i offset (%)

EF_{CO_2} = the CO_2 emission factor for each type of fossil fuel (t CO_2 /L, m^3 or other)

EF_{CH_4} = the CH_4 emission factor for each type of fossil fuel (t CH_4 /L, m^3 or other)

GWP_{CH_4} = Global Warming Potential of CH_4 (t CO_2e /t CH_4)

EF_{N_2O} = the N_2O emission factor for each type of fuel (t N_2O /L, m^3 or other)

GWP_{N_2O} = Global Warming Potential of N_2O (t CO_2e /t N_2O)

5.2.11 Heat

The emissions due to the production of heat that would have been required to compensate for the heat produced in the project condition are calculated as follows:

$$BE_{H,y} = \sum (Fuel_{i,y} \times EF_{Fuel_{CO_2}}); \sum (Fuel_{i,y} \times EF_{Fuel_{CH_4}} \times GWP_{CH_4}); \sum (Fuel_{i,y} \times EF_{Fuel_{N_2O}} \times GWP_{N_2O}) \quad (21)$$

$$Fuel_i = (H_y \times \%_i) / (NCV_{Fuel_i} \times \%_{eff})$$

Where:

$BE_{H,y}$ = baseline emissions due to the production of heat H that would have been required to compensate for the heat produced in the project condition (tCO₂e) in year y

$Fuel_{i,y}$ = the volume of fuel (fuel type i) to generate equivalent heat on an energy basis in year y (L, m³ or other)

H_y = the heat load produced under the project condition in year y (GJ)

$\%_i$ = the percentage of each type of fuel offset (%)

NCV_{Fuel_i} = the net calorific value of each type of fuel i offset by the project (GJ/L, m³ or other)

$\%_{eff}$ = the percentage of efficiency eff of the thermal energy heating system (%)

EF_{CO_2} = the CO₂ emission factor for each type of fuel (t CO₂/L, m³ or other)

EF_{CH_4} = the CH₄ emission factor for each type of fuel (t CH₄/L, m³ or other)

GWP_{CH_4} = Global Warming Potential of CH₄ (t CO₂e/t CH₄)

EF_{N_2O} = the N₂O emission factor for each type of fuel (t N₂O/L, m³ or other)

GWP_{N_2O} = Global Warming Potential of N₂O (t CO₂e/t N₂O)

5.3 Leakage

Restricting Biochar production to non-purpose-grown Feedstocks will prevent Leakage from upstream sources. Further, Leakage due to the depletion of soil organic Carbon Stocks and the potential for overharvesting organic agricultural residue is addressed in Appendix B. The provisions of this Protocol require documentation supporting the end use of Biochar, limiting the risk of Leakage by providing tangible, substantive evidence of stable sequestration.

Leakage could occur if, in the absence of the project, the Biomass Residues would have been used to generate renewable energy. When a Thermochemical Conversion unit is optimized to make both energy and Biochar, it will make less energy than a biomass facility which is optimized to make energy alone, due to Efficiency reductions. Fossil fuels could therefore be used to compensate for the loss of energy associated with diverting some energy production into the production of Biochar instead.

If Feedstock type w was used for bioenergy production, as in the default Baseline Scenario, the Project Proponent must account for the increase in emissions needed to compensate for the renewable energy that would have been produced in the Baseline Scenario. The Leakage emissions resulting from a loss in Efficiency of the biomass facility are calculated as follows:

$$Leakage_y = LE_{\eta_{loss}}$$

$$LE_{\eta_{loss}} = \sum (FS_{B,j,y} \times NCV_{j,y}) \times (\eta_B - \eta_P) \times EF_{Leakage} \quad (22)$$

Where:

$Leakage_y$ = Leakage that occurs in year y (t CO₂e)

$LE_{\eta_{loss}}$ = Leakage due to Thermochemical Conversion of Feedstocks that otherwise would have been used purely for the generation of energy (t CO₂e)

$FS_{B,j,y}$ = the amount of Feedstock type w diverted from baseline condition *bioenergy production* B in year y (t)

$NCV_{j,y}$ = net calorific value of the Feedstock type w processed at the Biochar facility in year y (GJ/t of dry matter)

η_B = the baseline B Efficiency of the biomass facility where the Biomass Residues would have been combusted before the implementation of the project (kWh/GJ or GJ/GJ)

η_P = the Efficiency of the Thermochemical Conversion facility in the project P condition (kWh/GJ or GJ/GJ)

$EF_{Leakage}$ = Emission factor for reduced energy production. If the Feedstock would have produced electricity in the baseline condition, use the regional electricity grid emission factor (t CO₂e/kWh). If thermal heat would have been produced in the baseline, use the emission factor associated with the most carbon intensive fuel that could reasonably be used to replace this biomass heat (t CO₂e/GJ)

5.4 Summary of GHG Emission Reduction and/or Removals

The emission reductions for this project activity are calculated as follows:

$$ER_{NET} = BE_{BASE} - PE_{PROJ} - Leakage_y \quad (23)$$

Where:

ER_{NET} = Net GHG emissions reductions and/or removals in year y

Y = year, where the baseline year is 0 and the first year of production is 1

BE_{BASE} = Baseline emissions in year y

PE_{PROJ} = Project emissions in year y

$Leakage_y$ = Leakage that occurs in year y

6.0 Monitoring

Project data monitoring requirements are shown in Attachment B

7.0 Reporting and Recordkeeping

7.1 Project Commencement

Attachment A must be completed, submitted, and approved prior to project commencement, as discussed in Section 2.1 and Section 3.5.

7.2 Recordkeeping

Attachment B can be used to collect, maintain, and document the required information. Information is to be kept for a period of 10 years after it is generated, or 7 years after the last verification.

7.3 Reporting

Attachment C can be used to report on project emission reductions. Reporting must be made on a monthly basis.

Project developers must report GHG emission reductions on an annual (12-month) calendar basis.

8.0 Verification

Project activities and GHG emission reductions must be verified and certified by a qualified third party prior to GHG emission reduction issuance. The verifier must review and assess the reported data to confirm that it adheres with all the requirements of this protocol; and determine that the emissions reductions are accurate, consistent, and credible. The third party verifier must be approved by the responsible entity that issues the emission reductions.

9.0 **Glossary of Terms**

Biochar:	Biochar is a solid material obtained through the thermochemical conversion of biomass in an oxygen-limited environment. Biochar differs from charcoal in the sense that its primary use is not for fuel, but for biosequestration or atmospheric carbon capture and storage. To be credited by this Methodology, Biochar must comply with all requirements of the most recent version of the International Biochar Initiative's Standardized Product Definition and Product Testing Guidelines for Biochar that is Used in Soil (aka IBI Biochar Standards).
Bioenergy:	Energy that is produced or originating from a recently living organism.
Biogenic:	Material that is produced or originating from a recently living organism.
Biomass Residues:	Biomass by-products, residues and waste streams from agriculture, forestry and related industries. (United Nations 2006). Any Biomass Residue meeting the Feedstock expectations of the IBI Biochar Standards (2013) is eligible for Biochar production under this methodology.
Bio-oil:	A liquid material obtained during the thermochemical conversion of biomass into biochar.
Chain of Custody:	Documenting/tracking the location and ownership history of feedstock step-by-step from its harvesting source to the final product of Biochar.
Contaminant:	An undesirable material in a biochar material or biochar feedstock that compromises the quality or usefulness of the biochar or through its presence or concentration causes an adverse effect on the natural environment or impairs human use of the environment (adapted from Canadian Council of Ministers of the Environment, 2005). Contaminants include fossil fuels and fossil-fuel-derived chemical

compounds, glass, and metal objects. (International Biochar Initiative 2013)

Developed/Industrialized Nation: There are no established conventions for designating “developed” or “developing” nations. This *Methodology* will follow the listing of industrialized nations and economies in transition included within Annex I Parties to the United Nations Framework Convention on Climate Change (UNFCCC) (United Nations 2012g).

Developing Nation: Following the definition of developed nation provided above, a Developing Nation will be considered to include all nations not listed within the Annex I parties to the UNFCCC (United Nations 2012g), which have been identified as Developing Nations or least developed countries.

Diluent/Dilutant: Inorganic material that is deliberately mixed or inadvertently comingled with biomass feedstock prior to processing. These materials will not carbonize in an equivalent fashion to the biomass. These materials include soils and common constituents of natural soils, such as clays and gravel that may be gathered with biomass or intermixed through prior use of the feedstock biomass. Diluents/dilutants may be found in a diverse range of Feedstocks, such as agricultural residues, manures, and Municipal Solid Wastes. (International Biochar Initiative 2012).

Efficiency: Efficiency is defined as the net quantity of useful energy generated by the energy generation system per quantity of energy contained in the fuel fired. In case of boilers that are used only for thermal energy generation (and not for power generation), the Efficiency is defined as the net quantity of useful heat generated per quantity of energy contained in the fuel fired in the boiler. In case of power plants producing only electric power (not cogeneration plants), the Efficiency is defined as the net electricity generated by the power plant as a whole divided by the quantity of energy contained in the fuel fired.

Feedstock: The material undergoing thermochemical conversion processes to create Biochar. Feedstock materials for Biochar consist of Biogenic

materials, but may also contain Diluents and no more than 2% by dry weight of Contaminants. (International Biochar Initiative 2013)

Fixed Carbon: Fixed Carbon is the component of the Biochar that has been shown to be stable through the application of the Ultimate Analysis or otherwise, as required in the Methodology to assess the stability of the sequestration of the carbon.

Gasification: A partial oxidation process that converts biomass into a mixture of synthesis gases composed of carbon monoxide, hydrogen and carbon dioxide.

Material Change: Material Changes in Feedstock reflect shifts in Feedstock type from one source of biomass to a distinctly different source of biomass. In mixed Feedstocks, whether processed or unprocessed, a 10% or greater shift in total Feedstock composition shall constitute a Material Change in Feedstock.

Material Changes in production processes reflect increases or decreases in process temperature or residence time. A Material Change in thermochemical production parameters has occurred if process temperature (also known as heat treatment temperature) changes by +/- 50°C, or if the thermochemical processing time (residence time) changes by more than 10%. See Appendix 4 of the IBI Biochar Standards (2013) for more information on how to determine Feedstock types that constitute a Material Change in type.

Mobile Biochar Operations: Mobile Biochar Operations are Biochar facilities that are built on a trailer or that otherwise can be relocated. These operations may be moved on a daily or similarly frequent basis.

Municipal Waste / Municipal Solid Waste (MSW): Solid, non-hazardous refuse that originates from residential, industrial, commercial, institutional, demolition, land clearing or construction sources (Canadian Council of Ministers of the Environment 2005). Municipal solid waste includes durable goods, non-durable goods, containers and packaging, food wastes and yard trimmings, and miscellaneous inorganic wastes (US Environmental

Protection Agency 2011).

Non-Biogenic:	Material that is not produced or originating from a recently living organism such as fossil fuels.
Project Proponent:	An individual or entity that undertakes, develops, and/or owns a project. This may include the project investor, designer, and/or owner of the lands/facilities on which project activities are conducted. The Project Proponent and landowner/facility owner may be different entities.
Proximate Analysis:	This methodological approach establishes the loss of material as samples are heated to predefined temperatures and typically reports volatile matter, Fixed Carbon, moisture content, and ash present in a fuel as a percentage of dry fuel weight. International Standards under ASTM exist for this measure; the relevant method is ASTM D1762-84 (2007).
Pyrolysis:	The thermochemical decomposition of a material or compound into a carbon rich residue, non-condensable combustible gases, and condensable vapors, by heating in the absence of oxygen, or low oxygen environment, without any other reagents, except possibly steam (United Nations 2012c).
Soil Amendment:	Any material added to soil to improve its physical and chemical properties, such as water retention, permeability, water infiltration, drainage, aeration and structure; for the goal of providing an improved rooting environment (Davis and Wilson 2005).
Solid Waste Disposal Site (SWDS)	Designated areas intended as the final storage place for solid waste. Stockpiles are considered a SWDS if (a) their volume to surface area ratio is 1.5 or larger and if (b) a visual inspection by the Department Of Environment or responsible governing body confirms that the material is exposed to anaerobic conditions (i.e. it has a low porosity and is moist).

Syngas:	Short for synthesis gas, syngas is a mixture of gases obtained during the thermochemical conversion of biomass into biochar.
Thermochemical Conversion:	The decomposition of biomass into biochar, bio-oils and syngas through controlled heating under low or no oxygen conditions.
Ultimate Analysis:	A quantitative analysis in which percentages of all elements in the substance are determined. International Standards under ASTM (www.astm.org) exist for Ultimate Analysis; the relevant method is ASTM D3176-09 (2005).
Verification Statement:	A verification statement provides assurance that, through examination of objective evidence by a competent and independent third party, a GHG assertion is in conformity with applicable requirements.
Verifier:	A competent and independent person, persons or firm responsible for performing the verification process. To conduct verification the verifier must be ACR-approved.

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Woolf, D., and Lehmann, J. 2012. Modeling the long-term response to positive and negative priming of soil organic carbon by black carbon. August 2012. Biogeochemistry. DOI: 10.1007/s10533-012-9764-6

11.0 Emission Factors

Table 2.0 Biochar Production Project -- Source Categories, GHG Sources, and GHG Emissions

Source	Associated GHGs	Included in GHG assessment boundary
Baseline		
Open Uncontrolled Pile Burning	CO ₂	Included
	CH ₄	Included
	N ₂ O	Included
In-field Decay and Decomposition	CO ₂	Included
	CH ₄	Included
	N ₂ O	Included
Landfill	CO ₂	Included
	CH ₄	Included
Biochar Production Project		
Transportation -- engine combustion of fossil fuels	CO ₂	Included
	CH ₄	Not included; negligible
	N ₂ O	Not included; negligible
Processing and Handling at Generation Site -- engine combustion of fossil fuels	CO ₂	Included
	CH ₄	Not included; negligible
	N ₂ O	Not included; negligible
Energy Recovery Facility	CH ₄	Not included for combustors; may need to be included for other energy processing types
	CO ₂	Included
	N ₂ O	Not included; negligible
Processing and Handling at Energy Recovery Facility -- engine combustion of fossil fuels	CO ₂	Included
	CH ₄	Not included; negligible
	N ₂ O	Not included; negligible
GHGs from conventional energy production displaced by energy from	Dependent on	Included

biomass waste	conventional energy source	
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Methane Emission Factors for Open Burning of Biomass

Reference / Burn Type	CH4 as reported by author	CH4 lb/dry ton fuel consumed
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U.S. EPA, Compilation of Air Pollutant Emission Factors, AP-42, Section 13.1, Prescribed Burning, October 1996, Table 13.1-3.

Broadcast Logging Slash

Hardwood (fire)	6.1 g/kg fuel consumed	12.2
Conifer short needle (fire)	5.6 g/kg fuel consumed	11.2
Conifer long needle (fire)	5.7 g/kg fuel consumed	11.4
Logging slash debris dozer piled conifer (fire)	1.8 g/kg fuel consumed	3.6

D.E. Ward, C.C. Hardy, D.V. Sandberg, and T.E. Reinhardt, Mitigation of prescribed fire atmospheric pollution through increased utilization of hardwoods, pile residues, and long-needled conifers, Part III, Report IAG DE-AI179-85BP18509 (PNW-85-423), USDA Forest Service, Pacific Northwest Station, 1989.

Broadcast Burned Slash

Douglas fir	11.0 lb/ton fuel consumed	11.0
Ponderosa pine	8.2 lb/ton fuel consumed	8.2
Mixed conifer	12.8 lb/ton fuel consumed	12.8
Pile and Burn Slash		
Tractor piled	11.4 lb/ton fuel consumed	11.4
Crane piled	21.7 lb/ton fuel consumed	21.7

U.S. EPA, Compilation of Air Pollutant Emission Factors, AP-42, Section 2.5, Open Burning,

October 1992, Table 2.5-5.

Unspecified	5.7 lb/ton material burned	10.4
Hemlock, Douglas fir, cedar	1.2 lb/ton material burned	2.4
Ponderosa pine	3.3 lb/ton material burned	6.6

W. Battye and R. Battye, Development of Emissions Inventory Methods for Wildland Fire, prepared under Contract EPA No. 68-D-98-046, Work Assignment No. 5-03, February 2002. (Based on data from D.E. Ward and C.C. Hardy, Smoke emissions from wildland fires, Environment International, Vol. 17, pp. 117-134, 1991.)

90% combustion efficiency	3.8 g/kg fuel consumed	7.6
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B. Jenkins, S. Turn, R. Williams, M. Goronea, et al., Atmospheric Pollutant Emission Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations, CARB Report No. A932-196, April 1996.

Ponderosa pine pile burn	1.3 g/kg dry fuel	1.7
Almond pruning pile burn	1.2 g/kg dry fuel	2.6
Douglas fire pile burn	1.9 g/kg dry fuel	3.0
Walnut pruning pile burn	2.0 g/kg dry fuel	4.0

R. Kopmann, K. von Czapiewski, and J.S. Reid, A review of biomass burning emissions, part I; gaseous emission of carbon monoxide, methane, volatile organic compounds, and nitrogen containing compounds, Atmos. Chem. Phys. Discuss., Vol. 5, pp. 10455-10516, 2005.

Literature search on biomass open burning	1 - 20 g/kg dry fuel	10.0
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Nitrous Oxide Emission Factors for Open Burning of Biomass

Delmas, R., Lacaux, J.P., Brocard, D. “Determination of biomass burning emission factors: methods and results,” Journal of Environmental Monitoring and Assessment, Vol. 38, 181-204, 1995. **0.00015 ton / ton dry**

Methane Emission Factors for Decay and Decomposition of Biomass

Mann, M. K., and P. L. Spath, “Life Cycle Assessment Comparisons of Electricity from Biomass, Coal, and Natural Gas,” 2002 Annual Meeting of the American Institute of Chemical Engineers. Golden, Colorado, National Renewable Energy Laboratory, 2002. **0.05 / ton dry**

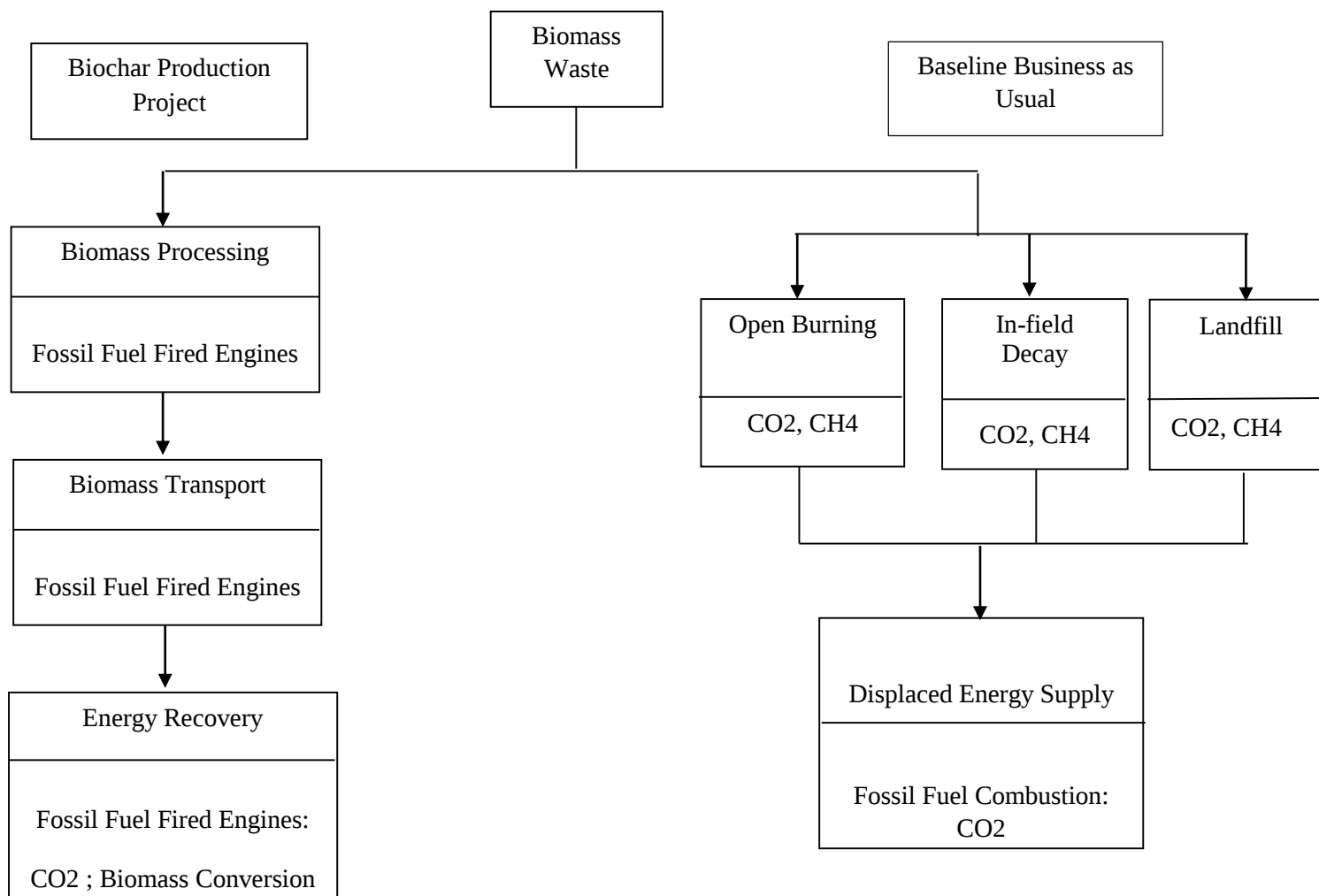
Assumes 9% carbon in biomass is converted to carbon in methane. Biomass has a molecular formula of $C_6H_{10}O_6$.

Nitrous Oxide Emission Factors for Decay and Decomposition of Biomass

Engineering judgment. At temperatures of in-field decay and decomposition, N_2O is expected to be negligible. Nitrogen in fuel will go to NH_3 . **0 /ton dry**

12.0 Attachments

Figure 1.0: System Boundary Definition



Attachment A: Project Definition

Date:				
Project Title:				
Project Developer:				
Project Address:				
Anticipated Project Dates:	Start Date:	End Date:		
Permitting Status:				
Biochar Feedstock Production & Disposal Information				
Composition of Biochar Feedstock (including moisture content)				
Historic, Current, and Anticipated Disposal Practice				
Biochar Feedstock Production Rate (green tons/day)				
Cost of Biochar Feedstock Processing and Transport (\$/green ton)				
Biochar Production Information				
Type of Energy Produced	Electricity	Heat	Fuels	Other
Name & Location of Energy Recovery Facility				
Generation Rate of Recovered Energy (MMBtu/day)				
Users/Purchasers of Recovered Energy				

Attachment B: Monitoring and Recordkeeping

Date:			
Project Title:			
Project Developer:			
Start Date of Monitoring Period:		End Date of Monitoring Period:	

Monitoring and Parameter Measurements

Parameter	Description	Data Unit	How Measured	Measurement Frequency	Reported Measurement
$FS_{i,j,y}$	Total amount of Feedstock type j diverted from baseline condition i in year y . (dry weight)	t	Sample the Feedstock composition, using the Feedstock categories j , and weigh each Feedstock fraction	Continuously, aggregated monthly or annually	
$p_{n,j,y}$	Weight fraction of the Feedstock type j in the sample n collected during year y (dry weight)	t	Sample the Feedstock composition, using the Feedstock categories j , and weigh each Feedstock fraction	Minimum of three samples every three months	
Z	Number of samples collected during year y	N/A	Minimum of three samples every three months	Continuously, aggregated annually	
$M_{j,y}$	Moisture content percent of Biochar	%	Sampling and analysis of	Measurements must be	

Parameter	Description	Data Unit	How Measured	Measurement Frequency	Reported Measurement
	type w in year y		produced Biochar	repeated for each subsequent year of production or after any material change in feedstock or process activity	
f_y	Fraction of methane capture at the SWDS and flared, combusted or used in another manner that prevents the emissions of methane to the atmosphere in year y	%	N/A	Annual	
$E_{R,y}$	Electricity will be produced at off-site grid connected generation facilities in the baseline to cover the amount of renewable electricity being generated from the Biochar output in the project condition	kWh	Direct metering of the net quantity of renewable electricity generated in the project condition and used off-site in year y	Continuous metering	
O_y	Volume of bio-oil produced in the project condition	L, m3, or other	Direct metering or reconciliation of volume in	Continuous metering or monthly	

Parameter	Description	Data Unit	How Measured	Measurement Frequency	Reported Measurement
	in year y. This parameter is used to calculate the baseline emissions due to the use of fossil oil that would have been required to compensate for the bio-oil produced in the project condition		storage (including volumes received), or monthly invoices filed for Verification	reconciliation	
G_y	Volume of syngas produced in the project condition in year y. This parameter is used to calculate the baseline emissions due to the use of fossil gas that would have been required to compensate for the syngas produced in the project condition	L, m3, or other	Direct metering or reconciliation of volume in storage (including volumes received), or monthly invoices filed for Verification	Continuous metering or monthly reconciliation	
$\%_i$	Percentage of each type of fuel offset from either the production of bio-oil, syngas or heat in the project condition.	%	Represents most reasonable means of estimation	Once	
H_y	Heat load produced under the project condition in year	GJ	Direct metering of thermal energy delivered to the end user in	Monthly	

Parameter	Description	Data Unit	How Measured	Measurement Frequency	Reported Measurement
	y. This parameter is used to calculate the baseline emissions due to the production of heat that would have been required to compensate for the heat produced in the project condition.		the project condition		
Fuel _p , Fuel _{py} , Fuel _{OP} , Fuel _{GP} , Fuel _{BL} , Fuel _{OU} , Fuel _{GU}	Volume of each type of fuel consumed in year y. This volume of fuel is adjusted for both functional equivalence and units of productivity.	Gallons	Direct metering or reconciliation of volume in storage (including volumes received), or monthly invoices filed for Verification	Continuous metering or monthly reconciliation	
E _{G,y}	The quantity of grid electricity consumed in the project condition in year y	kWh	Direct metering, aggregated monthly	Continuous metering	
BC _{j,y}	Mass of Biochar type <i>j</i> produced from the facility in year y	Tonne	Direct measurement of mass of Biochar produced	Continuous, aggregated monthly or annually	
M _{j, y}	Moisture content of Biochar <i>j</i> in year y	%	Measurement of materials conducted as prescribed by the Standard Test Method for Estimating	Annually, or with any Material Change of Feedstock type or production	

Parameter	Description	Data Unit	How Measured	Measurement Frequency	Reported Measurement
			Biochar Carbon Stability (International Biochar Initiative 2013a).	process	
C _{org}	Percent organic carbon of Biochar <i>j</i> in year <i>y</i>	%	Measurement of materials conducted as prescribed by the Standard Test Method for Estimating Biochar Carbon Stability (International Biochar Initiative 2013a)	Annually, or with any Material Change of Feedstock type or production process	
NCV Fuel _i	Net calorific value of each type of fuel <i>i</i> offset by the project	GJ/L, M ³ or other	Measurement of the quantity of heat produced by combustion when that water produced by combustion remains gaseous	Continuous, aggregated monthly or annually	

Attachment C: Reporting

Date:	
Project Title:	
Project Developer:	
Reporting Period:	

Parameter	Description	Data Unit	Reported Value
EF_{CO_2}	The CO_2 emissions factor for each type of fossil fuel	t CO_2 /L, m^3 or other	
EF_{CH_4}	The CH_4 emission factor for each type of fossil fuel	t CO_2 /L, m^3 or other	
EF_{N_2O}	The N_2O emission factor for each type of fossil fuel	t CO_2 /L, m^3 or other	
GWP_{CH_4}	Global Warming Potential of CH_4	t CO_2e /t CH_4	
GWP_{N_2O}	Global Warming Potential of N_2O	t CO_2e /t N_2O	
$E_{G,y}$	Quantity of grid G electricity consumed in the project condition in year y	MWh	
EF_{Grid}	Regional electricity grid emission factor	t CO_2e /MWh	
$FS_{PNBi,y}$	Amount of non-biogenic Feedstock (feedstock type i) Pyrolyzed PNB in year y	t	
$FS_{B,j,y}$	Amount of	t	

Parameter	Description	Data Unit	Reported Value
	Feedstock type w diverted from baseline condition bioenergy production B in year y		
$FS_{A,j,y}$	Fraction of Feedstock type w diverted from aerobic decomposition A in year y	t	
$EF_{ACH_4,y}$	Emission factor for methane CH_4 per tonne of waste diverted from aerobic decomposition A , valid in year y	t CH_4 /t	
$EF_{AN_2O,y}$	Emission factor for nitrous oxide N_2O per tonne of waste diverted from aerobic decomposition A , valid in year y	t N_2O /t	
ϕ	Model correction factor to account for model uncertainties for year, y	N/A	
f_y	Recovered methane at the landfill in year y	%	
OX	Oxidation factor (reflecting the amount of methane from SWDS that is oxidized in the soil)	N/A	

Parameter	Description	Data Unit	Reported Value
	or other material covering the waste)		
F	Fraction of methane in the SWDS gas	%	
DOC _{f,y}	Fraction f of degradable organic carbon that decomposes under the specific conditions occurring in the SWDS for year y	N/A	
MCF _y	Methane conversion factor for year y	N/A	
FS _{an,j,y}	Amount of Feedstock type w prevented from baseline condition anaerobic decomposition AN in an SWDS in year y	t	
DOC _j	Degradable organic carbon in the Feedstock type w	N/A	
k _j	Decay rate for the Feedstock type w	l/yr	
FS _{C,j,y}	amount of Feedstock type w prevented from baseline condition combustion C in year y	t	
E _{R,y}	Net quantity of renewable electricity R generated in the	t CO ₂ e/MWh	

Parameter	Description	Data Unit	Reported Value
	project condition and used off-site in year y		
$\%_{\text{eff}}$	Percentage of efficiency eff of the thermal energy heating system	%	
LE_{loss}	Leakage due to Thermochemical Conversion of Feedstocks that otherwise would have been used purely for the generation of energy	t CO ₂ e	
$NCV_{j,y}$	Net calorific value of the Feedstock type w processed at the Biochar facility in year y	GJ/t of dry matter	
η_B	Baseline B Efficiency of the biomass facility where the Biomass Residues would have been combusted before the implementation of the project	kWh/GJ or GJ/GJ	
η_P	Efficiency of the Thermochemical Conversion facility in the project P condition	kWh/GJ or GJ/GJ	
EF_{Leakage}	Emission factor for reduced energy production.	t CO ₂ e/kWh or tCO ₂ e/GJ	

13.0 Appendix

Appendix A: Standard test method for estimating Biochar carbon stability (BC_{+100})

Scope

This test method provides the calculations needed to estimate the amount of carbon that is expected to remain in Biochar after a period of 100 years (BC_{+100}), which is considered “stable” for the purpose of determining a GHG emissions reduction value. This stable portion of the carbon sequestered in Biochar is deducted from Project Emissions in Equation 1. As part of that method, this covers the determination of hydrogen, total carbon and organic carbon in a sample of Biochar.

This document builds upon previous work coordinated by The International Biochar Initiative (IBI) to develop the “*Standardized Product Definition and Product Testing Guidelines for Biochar that Is Used in Soil*” (International Biochar Initiative 2012). This document constrains its scope to materials with properties that satisfy the criteria for Biochar as defined by the IBI Standards (International Biochar Initiative 2012).

This Standard test method does not purport to address all of the safety concerns, if any, associated with use of Biochar. It is the responsibility of the user of this Standard test method to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. The minimum safety equipment should include protective gloves and sturdy eye and face protection.

Terminology

Biochar – A solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment (International Biochar Initiative 2012) that complies with the definition in the *IBI Biochar Standards* 2012.

BC_{+100} – The fraction of carbon present in Biochar that is expected to remain in soil for at least 100 years (Kyoto Protocol 1998) when added to soil.

Total carbon – The total amount of carbon in a sample, both organic and inorganic.

Organic carbon – The fraction of carbon in the sample that is derived from biogenic material.

Inorganic carbon – The fraction of material derived from geologic or soil parent material (Schumacher, 2002), which is mineral. Carbon Dioxide, salts of carbonates and soluble carbonates are the most common forms of inorganic carbon.

Summary of Test Method

The sample is prepared in a specified manner (see section 6). An elemental analyzer is used to determine hydrogen and total carbon in the Biochar sample. Inorganic carbon is measured and subtracted from total carbon to estimate the organic carbon (C_{org}) content, which allows the calculation of the molar ratio of hydrogen to organic carbon (H/C_{org}). Finally, the calculated

H/C_{org} value is converted into its equivalent BC₊₁₀₀ value – based on the report Biochar Carbon Stability Test Method: An Assessment of Methods to Determine Biochar Carbon Stability – needed to calculate the amount of stable (+100) Biochar carbon sequestration (C_{BS,y}) as used in equations (1) and (11) GHG.

Significance and Use

The production of Biochar can qualify as a carbon sequestration strategy because of the increased stability of Biochar carbon that is obtained through Thermochemical Conversion. This test method allows for the determination of the GHG emission reduction that could be claimed through the production of Biochar, based on the carbon estimated to remain stable in Biochar after 100 years.

Apparatus and Reagents

Use only reagents of recognized analytical grade.

- 105°C ±2 drying oven
- 200°C heat resistant drying vessel (high silica or porcelain evaporating dish)
- Balance (0.01 g capacity)
- Mortar and Pestle
- #10 (2 mm) Sieve
- Elemental analyzer for Hydrogen and Carbon
- Rapid Carbonate Analyzer (ASTM D4373 fig.2)
- 1 N HCl
- Reagent Grade Calcium Carbonate (CaCO₃)
- 20mL Graduated Cylinder

Sample Collection and Handling

Development of appropriate sampling plans

As mentioned in the United States Environmental Protection Agency (EPA) Manual SW-846 (US Environmental Protection Agency 2006), which addresses the development and implementation of a scientifically credible sampling plan and the documentation of the chain of custody for such a plan, the initial, and perhaps most critical, element in a program designed to evaluate the physical and chemical properties of a sample (in this case, of Biochar), is the sampling plan.

A sampling plan is usually a written document that describes objectives and tasks and identifies how the individual tasks will be performed. The SW-846 Manual (US Environmental Protection Agency 2006) suggests that a sampling plan should be designed with input from the various sectors involved in the project, which include: regulatory sampling, end-users, field team members, analytical chemists, process engineers or equivalent, statisticians and quality assurance representatives.

The referenced manual describes a number of sampling procedures (simple, stratified, systematic random, composite), of which one must be selected which is most appropriate, according to the characteristics of the sampled object. The team involved in the elaboration of the sampling plan must therefore consult the SW-846 Manual during the development of a sampling plan. This test method proposes the use of composite sampling, as it will help reduce the physical/chemical heterogeneity of a sample.

Sample selection and frequency

The sample shall be selected so as to be representative of all the material contained in a production lot. This is achieved by employing a composite sampling procedure (US Environmental Protection Agency 2006), which requires the collection of multiple random sub-samples from the final volume of produced Biochar, and mixing them together to obtain a homogeneous sample of no less than 500 g. It needs to be demonstrated that the sample size is representative of the whole production lot, via statistical analysis. Samples must be taken:

- Annually; or
 - After a material change in Feedstock; or
 - After a material change in thermochemical production parameters;
- Whichever is more frequent.

Material changes (International Biochar Initiative 2012, section 6.2) in Feedstock reflect shifts in Feedstock type from one source of biomass to a distinctly different source of biomass. See Appendix 4 of the IBI Standards (International Biochar Initiative 2012) for more information on how to determine Feedstock types that constitute a “material change”. In mixed Feedstocks, whether processed or unprocessed, a 10% or greater shift in total Feedstock composition shall constitute a material change in Feedstock.

Material changes in production processes reflect increases or decreases in process temperature or residence time. A material change in thermochemical production parameters has occurred if process temperature (also known as Heat Treatment Temperature) changes by $\pm 50^{\circ}\text{C}$, or if the thermochemical processing time (residence time) changes by more than 10% of the initial processing time.

Testing of Biochar materials should occur after thermochemical processing is complete and before final shipment. If the material is intended to be mixed with another material, testing of the Biochar material must occur before mixing or blending with any other product.

Additional Considerations for Sampling

Sampling practices should follow a composite sampling procedure (well-mixed batch), where a single sample (or group of samples) is taken to represent a specific period of production time. Frequency of sampling depends on the appropriate number of samples needed to achieve the necessary precision (at least 95% confidence level). Precision is improved by increasing the number of samples while maintaining a sampling pattern to guarantee a spatially uniform distribution. The number of samples required is the least amount to generate a sufficiently precise estimate of the true mean concentration. The number of samples required must also

demonstrate that the upper limit of the confidence interval of the true mean is less than applicable regulatory threshold value. Detailed calculations for the number of samples required can be found within the US EPA SW-846 manual (US Environmental Protection Agency 2006) and within the US Composting Council TMECC composting methods manual (US Composting Council 2001).

Chain of Custody form

Chain of custody forms and procedures should be used with all environmental or regulatory samples. These forms are used to track sampling and handling from the time of collection through laboratory analysis and data reporting. The form should include, at a minimum: collector's name, signature of collector, date and time of collection, location (place and address) of collection, identification of sample to be used in all reporting, requested analysis (code number) and signature of people involved in the chain of possession (a sample form is included at the end of this document).

Sample preparation

The sample must leave the production facility in a sealed, moisture-proof container for transport to the analyzing facility, to prevent moisture loss/gain before it is to be analyzed.

Sample Analysis Procedures

Materials

Make replicate determinations and run appropriate Standard reference materials (SRM) with each analysis to ensure quality.

Moisture

Zero the balance. Place a 200°C heat resilient vessel (high silica or porcelain evaporating dish) on the balance, and record the mass to the nearest 0.01g (m_v).

Working quickly so as to not lose or gain moisture during preparation, mix the sample and place no less than 5 g in the vessel. Record the mass of the vessel and as-received sample (m_{sr}) to the nearest 0.01 g. Immediately place the vessel containing the sample in a 105°C oven until a constant mass is reached.

Remove the vessel and sample from the oven and let cool in a desiccator until it reaches room temperature. Record the mass of the vessel and dried sample (m_{sd}) to the nearest 0.01g.

In a clean and dry mortar and pestle place your dried sample and grind it as many times as necessary until the material passes through a 2mm sieve.

The dried and ground sample will be separated into two sub-samples, with masses determined by the requirements of the specific equipment to be used for the measurement of H, C_{tot} and C_{org} . Sample quantities must be large enough to complete all analyses. One sub-sample is used to determine the hydrogen and total carbon and the other to determine organic carbon content via inorganic carbon measurement and subtraction from measured total carbon.

Hydrogen and total carbon

One of the sub-samples is tested for hydrogen and total carbon using an elemental analyzer, employing a dry combustion method of molecular mass determination, according to the manufacturer's protocol.

Record the initial sample mass, as well as the hydrogen and total carbon percentages.

Inorganic carbon

The second sub-sample is used to determine the inorganic carbon content. It is treated with 1N HCl in a closed vessel. Carbon Dioxide gas is evolved during the reaction between the acid and carbonate fraction of the specimen. The resulting pressure is proportional to the carbonate content of the specimen. This pressure is measured using a pre-calibrated pressure gauge based on reagent grade calcium carbonate, according to (ASTM D4373).

Weigh and record the mass of the second sub-sample, which is then inserted into the reactor. Following insertion of a Biochar sub-sample into the reactor, lower the 20 mL filled acid container carefully into the reactor without spilling. Seal the reactor and close the pressure-release valve. Tilt the reactor to spill the acid onto the sample and swirl to mix until reaction is complete (~2 to 3 minutes). Monitor the pressure gauge to ensure that the reaction vessel is completely sealed. Record the pressure. Repeat this procedure using increasing masses of the reagent grade calcium carbonate Standard (0, 0.2, 0.4, 0.6, 0.8 and 1.0 g), register values and plot a graph of CaCO₃ mass versus reactor pressure. Calibrate the pressure dial directly in percent inorganic carbon along the following range: 0, 2.4, 4.8, 7.2, 9.6, and 12%. These inorganic carbon percentages correspond directly to the masses of CaCO₃ used in the Standard calibration, since pure calcium carbonate is 12% carbon (please refer to the chemical properties listed for this reagent to determine its specific carbon content, and specify the accuracy of the equipment). Remove acid with heat and/or vacuum.

Record the inorganic carbon content as interpreted from the pressure calibration curve.

Calculations

Moisture

Calculate the moisture content as follows:

$$M = \left[\frac{(m_{sr} - m_{sd})}{(m_{sr} - m_v)} \right] * 100 \quad (25)$$

Where:

M = Moisture content (%)

m_{sr} = Mass of vessel and as received sample (g)

m_{sd} = Mass of vessel and dried sample (g)

m_v = Mass of vessel (g)

Hydrogen and total carbon

Simply record the results for H and C_{tot} from the elemental analyzer in percent units.

Organic carbon

Calculate the organic carbon as follows:

$$C_{org} = (C_{tot} - C_{inorg}) \quad (26)$$

Where:

C_{org} = Percent organic carbon in the sample.

C_{tot} = Percent total carbon

C_{inorg} = Percent inorganic carbon

Hydrogen to Organic carbon molar ratio

Calculate the Hydrogen to Organic carbon molar ratio as follows:

$$H/C_{org} = \frac{(\%H/1)}{(\%C_{org}/12)} \quad (27)$$

Where:

H/C_{org} = Hydrogen to organic carbon molar ratio

$\%H$ = Hydrogen mass of the sample (in %)

$\%C_{org}$ = Organic carbon mass of the sample (in %)

Emissions reduction

Calculate the GHG emissions reduction (ER) to be claimed as follows:

Convert the calculated H/C_{org} value to the equivalent BC_{+100} value as follows:

H/C_{org}	BC_{+100}
<0.4	70%
0.4-0.7	50%

Multiply the calculated BC_{+100} value to calculate GHG emissions reduction as follows:

$$ER = W_{LOT} \times \frac{C_{org}}{100} \times \left(\frac{BC_{+100}}{100} \right) \times \left(\frac{(1000M)}{100} \right) \times \frac{44}{12} \times 0.95 \quad (28)$$

Where:

ER= Greenhouse Gas emissions reduction, expressed in tons of carbon dioxide equivalent (ton CO₂eq).

W_{LOT} = Weight of the production lot from where the sample was taken (in metric tons)

C_{org} = Organic carbon calculated from the sample

BC_{+100} = Biochar carbon stable for at least 100 years

M = Moisture content (%)

44/12 = Molar ratio of carbon dioxide to carbon.

0.95 = correction factor due to possible positive priming effect¹

(Alternatively, use calculated values of C_{org} , B_{+100} , and M in Equation 11 to determine $C_{BS,j,y}$ for Equation 1.)

Precision and Bias for Hydrogen, Total carbon and Inorganic carbon methods

Precision and Bias

Precision: To date, no inter-laboratory testing program has been conducted using this method to determine multi-laboratory precision.

Bias: The bias of the procedure in this test method has not yet been conducted.

Conservativeness and the Use of Confidence Intervals

The BC_{+100} calculations are based on the lower limit of a 95% confidence interval of a regression performed to relate H/ C_{org} values registered from Biochar samples (n=37), based on a two-component double exponential model. They are therefore considered conservative estimations.

Documentation of Chemical Analysis

Maintaining a written and/or visual (photos, video, other) registry of the complete process, regarding the values obtained in each step for each variable is required in order to provide documented data for third-party Verification bodies.

Keywords

¹ Support Information section 1 of the report "Biochar Carbon Stability Test Method: An assessment of methods to determine Biochar carbon stability"

Biochar, BC₊₁₀₀, hydrogen, total carbon, organic carbon, hydrogen-to-organic carbon molar ratio.

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- (3) Kyoto Protocol (1998) COP3 Decision 2/CP.3 Methodological issues related to the Kyoto Protocol, paragraph 3.
- (4) Schumacher, B. (2002) Methods for determination of Total Organic carbon (TOC) in soils and sediments. US Environmental Protection Agency (EPA), Environmental Sciences Division National Exposure Research Laboratory, Office of Research and Development.
- (5) US Composting Council (2001) Test Methods for the Examination of Composting and Compost (TMECC) Composting methods Manual, Field Sampling of Compost Material Section 02.01-C.
- (6) US Environmental Protection Agency (2006), Test Methods for Evaluating Solid Waste, Physical/Chemical methods, Chapter 9.

Appendix B: Justification for the “Standard test method for estimating Biochar carbon stability (BC +100)”

A. Budai²; A. R. Zimmerman³; A.L. Cowie⁴; J.B.W. Webber⁵; B.P. Singh⁶; B. Glaser⁷; C. A. Masiello⁸; D. Andersson⁹; F. Shields¹⁰; J. Lehmann¹¹; M. Camps Arbestain¹²; M. Williams¹³; S. Sohi¹⁴; S. Joseph¹⁵, Miguel Rodriquez¹⁶

Abstract

Twenty seven methods currently used to characterize Biochar were assessed in terms of their usefulness to determine the stability of Biochar carbon in the environment. The International Biochar Initiative (IBI), which led the effort, gathered fourteen experts in different fields of Biochar relevant to stability, who guided the process for obtaining a simple, yet reliable, measure for Biochar stability. Important requisites were defined for the test, including cost, repeatability and availability. Identification of a cost-effective, scientifically valid test to measure the stable carbon component of Biochar is imperative to distinguish Biochar from non-Biochar (non-stable) materials, and to develop a Biochar offset Methodology for carbon markets. The stability of Biochar carbon in soils makes it a highly promising product for consideration as a strategy for climate change mitigation. The definition of the variable BC+100, which represents the amount of Biochar carbon that is expected to remain stable after 100 years, along with predictions of stability based on simple (Alpha) and more sophisticated (Beta) methods, allowed to correlate a molar ratio (H/C_{org}) to the relative stability of Biochar. The process for identifying the Biochar Carbon Stability Test Method is summarized here, and the method itself is available as a separate, technical document (Appendix A).

Introduction

The stability of Biochar is of fundamental importance in the context of Biochar use for environmental management for two primary reasons: first, stability determines how long carbon applied to soil, as Biochar, will remain in soil and contribute to the mitigation of climate change; second, stability will determine how long Biochar will continue to provide benefits to soil, plant,

² Norwegian Institute for Agricultural and Environmental Research – Bioforsk, Høgskoleveien 7, N-1432 Ås, Norway

³ Department of Geological Science, University of Florida, 241 Williamson Hall, P. O. Box 112120, Gainesville, Florida 32611-2120, United States

⁴ Rural Climate Solutions, University of New England, NSW Department of Primary Industries, Armidale 2351, Australia

⁵ School of Physical Sciences, University of Kent, CT2 7NH, UK

⁶ NSW Department of Primary Industries, PO Box 100, Beecroft NSW 2119, Australia

⁷ Soil Biogeochemistry, Martin-Luther-Univ. Halle-Wittenberg, von-Seckendorff-Platz 3, 06120 Halle, Germany

⁸ Department of Earth Science, 6100 Main St. MS 126, Rice University, Houston, TX 77005, United States

⁹ EcoEra, Orkestergatan 21 181, 42139 Göteborg, Sweden

¹⁰ Control Laboratories, Inc., 42 Hangar Way, Watsonville, CA 95076, United States

¹¹ Department of Crop and Soil Sciences, Cornell University, Ithaca, NY 14853, United States

¹² Institute of Natural Resources, Massey University, Palmerston North 4442, New Zealand

¹³ Biochar Solutions Inc., PO Box 2048, Carbondale, CO 81623, United States

¹⁴ UK Biochar Research Centre (UKBRC), School of GeoSciences, University of Edinburgh, Crew Building, The King's Buildings, Edinburgh, EH9 3JN, UK

¹⁵ School of Material Science and Engineering, University of New South Wales, 2052 Sydney, Australia

¹⁶ International Biochar Initiative, 640 Brook Run Drive, Westerville, OH, 43081, United States

and water quality (Lehmann et al., 2006). Biochar production and application to soil can be, in many situations, a viable strategy for climate change mitigation. Conversion of biomass carbon (C) to Biochar C via Thermochemical Conversion can lead to sequestration of about 50% of the initial C compared to the low amounts retained after burning (3%) and biological decomposition (<10–20% after 5–10 years) (Lehmann et al, 2006, Figure B-1), with the entirety of uncharred biomass being most likely decomposed after a century, which is a relevant time frame for the purpose of the stability test, as presented in subsequent sections.

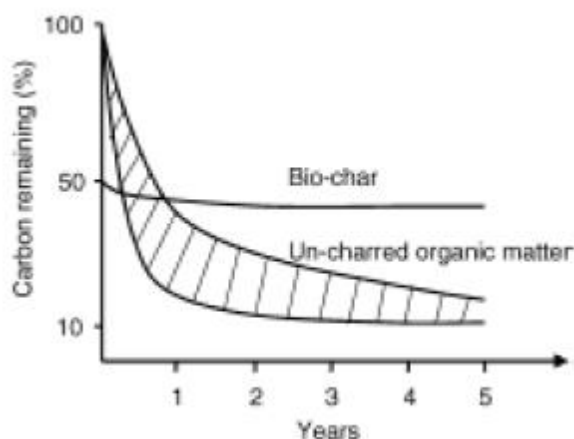


Figure B-1. Schematic of Biochar and biomass degradation patterns. Source: Lehmann et al. (2006)

Biochar has been found to mineralize in soil much slower than the organic material it is produced from. The Mean Residence Time (MRT) of different Biochars has been found to fall mostly in the centennial to millennial scales, as shown in Table B-1, with some studies showing estimations of decadal scales. The difference in these data is not the result of random variability but to a large extent the product of different materials and to different environmental and experimental conditions.

Table B-1. Mean Residence Time (MRT) of Biochar across studies.

Publication	Scale of estimated MRT (years)
Masiello and Druffel, 1998	Millennial (2,400 – 13,900)
Schmidt et al., 2002	Millennial (1,160 – 5,040)
Cheng et al., 2006	Millennial (1,000)
Laird, 2008	Millennial (1,000's)
Cheng et al., 2008	Millennial (1,335)
Kuzyakov et al., 2009	Millennial (2,000)
Major et al., 2010	Millennial (3,264)
Novak et al., 2010	Millennial (1,400-51,000)
Liang et al., 2008	Centennial to millennial (100-10,000's)
Zimmerman, 2010	Centennial to millennial (100-

	100,000)
Baldock and Smernik, 2002	Centennial (100-500)
Hammes et al., 2008	Centennial (200-600)
Schneider et al., 2011	Centennial (100's)
Hamer et al. 2004	Decadal (10's)
Nguyen et al. 2008	Decadal (10's)

Objective

The goal of this effort was to develop a method for testing and quantifying the mineralization of carbon in Biochar, by specifying the amount of C that is predicted to remain present in soil 100 years¹⁷ after land application, which for the purposes of the stability test is termed BC₊₁₀₀. The fraction of carbon in Biochar that mineralizes during the same time period is termed BC₋₁₀₀. Selection of methods was based on the following:

- Only analytical tests for Biochar stability that have been published in the peer-reviewed literature before the final issuance of this document were considered;
- Sampling procedures and test methods had to be considered cost-effective; and
- All assumptions made during the development of this test method followed the principle of conservativeness, i.e. the Methodology should in every instance utilize conservative approaches in order to avoid over-estimating the stability of Biochar carbon.

Scope of Work

The effort was built upon previous work completed by The International Biochar Initiative (IBI) to develop “**Standardized Product Definition and Product Testing Guidelines for Biochar That Is Used In Soil**” (*IBI Biochar Standards, 2012*). The present document constrains its scope to materials with properties that satisfy the criteria for Biochar as defined by the IBI Standards.

This test method considers only the carbon stabilized in Biochar via Thermochemical Conversion. Neither Biochar impacts on plant productivity, nor any effects on native soil Carbon Stocks or vice-versa (i.e. positive or negative priming) are included (Figure B-2), because scientific evidence is insufficient at this time to determine the direction and magnitude of these processes. Biochar may stabilize native soil organic carbon by sorbing organic compounds (Smernik, 2009). There are, however, cases where Biochar addition to soil can produce an undesirable "positive priming effect" (Hamer et al., 2004; Wardle et al., 2008; Kuzyakov et al., 2009; Zimmerman et al., 2011; Cross and Sohi, 2011; Woolf and Lehmann, 2012; Singh et al., 2012), causing the release of additional CO₂ from soil. However, Woolf and Lehmann (2012) estimated that no more than 3 to 4% of initial non-pyrogenic SOC might be mineralized due to

¹⁷ Global Warming Potential (GWP) of Greenhouse gases (GHG) is assessed over a 100-year time horizon. One hundred years is commonly used to define permanence in carbon offset markets (e.g. Mechanisms under the Kyoto Protocol (Clean Development Mechanism - CDM, Joint Implementation - JI), Australia's Carbon Farming Initiative).

priming by Biochar over 100 years. Even though this effect may be small compared to the possible increase in C sequestration from the negative priming effect, positive priming was conservatively taken into account with the 0.95 correction factor in equation (33) of the GHG Methodology.

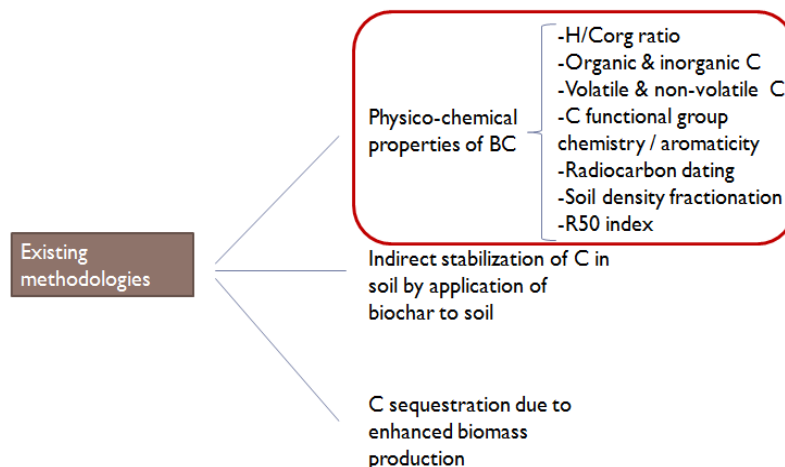


Figure B-2. Scope of work for the test method.

Even though there is evidence of increased net primary productivity (NPP) of soils after Biochar addition (Lehman et al., 2006; Major et al., 2010), carbon sequestration due to enhanced biomass production was not included because insufficient data are available to quantify the effects of Biochar additions to soil on crop productivity, which is likely to vary widely between soil types, Feedstock and environments (Van Zwieten et al., 2010; Jeffery et al., 2011). Additionally, the longevity of the measured short-term impacts of Biochar on NPP is unknown. Furthermore, C sequestered in biomass of annual crops and pasture cannot be considered stable, mainly due to its fast turnover rate. The decision not to include these also reflects the conservative approach of this effort.

Definitions

Types of methods

Through a review made by the Expert Panel consisting of fourteen Biochar experts, test methods were categorized into three groups: (1) Alpha methods, which may allow routine estimation of the BC_{+100} at minimal costs; (2) Beta methods, which directly quantify BC_{+100} and may be used to calibrate Alpha methods; and (3) Gamma methods, which may provide the physiochemical underpinning for the Alpha and Beta methods. These categories of methods are justified and described below.

Alpha methods

Alpha methods are defined as those which provide a simple and reliable measure of the relative stability of carbon in Biochar, that are readily available, at a cost of less than 100 US dollars (USD) (defined as feasible by the Expert Panel) and within a timeframe of minutes or hours to, at

maximum, a few days. Alpha methods are intended to be undertaken by a certified laboratory to be used by Biochar producers.

Alpha methods do not provide an absolute measure of stability; rather, they assess a property (usually chemical or physical) that is related to stability. Alpha methods must be calibrated through comparison with Beta and/or Gamma methods.

Some Alpha methods have already been developed (“Alpha-1”) and were found to be strongly related to the properties determined by the Beta and Gamma methods. It is expected that more Alpha methods will emerge as Biochar stability research continues to develop, which could be placed in a category called “Alpha-2” methods.

The results of any Alpha method must correlate – ideally linearly – with results of at least one Beta (calibration) method, as well as those of the applicable Gamma methods. Some possible Alpha-1 methods are briefly described and discussed below.

Hydrogen to Organic Carbon Molar Ratio (H:Corg) (Enders et al., 2012; IBI, 2012) and Oxygen to Carbon Molar Ratio (O:C) (Spokas, 2010):

Both ratios reflect the physico-chemical properties of Biochar related to stability, as the proportion of elemental compounds (H and O) relative to carbon (C) present in Biochar. These elemental constituents of Biochar can be measured routinely, using an elemental analyzer, based on the manufacturer’s protocol.

Increasing production temperatures lead to lower H/C and O/C ratios (Krull et al., 2009; Spokas, 2010), as the abundance of C relative to H and O increases during the Thermochemical Conversion process (Figure B-3).

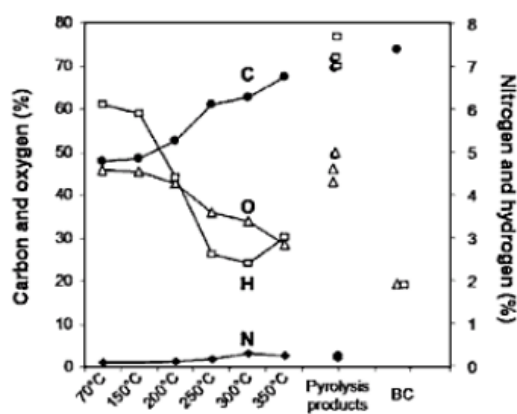


Figure B-3. Changes in Biochar elemental composition with varying Thermochemical Conversion temperatures. Source: Krull et al. (2009).

Materials with low H/C and O/C values are graphite-like materials (i.e. soot, black carbon, activated carbon), which exhibit high stability compared to uncharred biomass, which possesses high H/C and O/C values (Figure B-4) and low resistance to degradation. Hence, as Biochars resemble graphite-like materials, characterized by low H/C and O/C ratios, they are expected to

be more stable or inert, and less prone to mineralization than uncharred organic matter (Masiello, 2004).

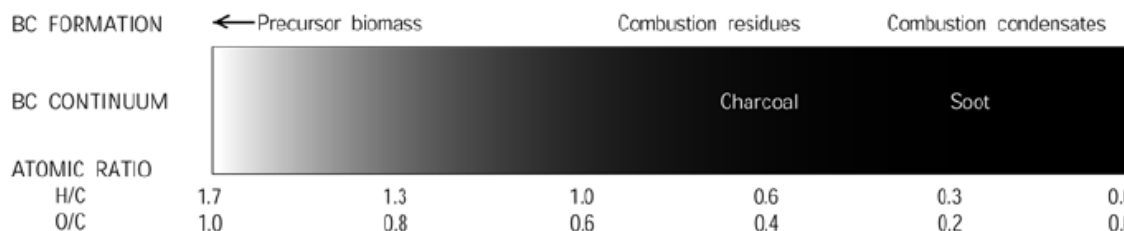


Figure B-4. Physical characteristics and ratios related to Biochar stability. Source: Adjusted from Hammes et al. (2007)

These two ratios can be plotted in a two-dimensional Van Krevelen diagram, which is a graphical representation of Biochars, based on elemental composition. In a study by Schimmelpfennig and Glaser (2012), different Biochars are characterized based on the relation between the measured H/C and the O/C ratios, and compared to different types of coals (Figure B-5).

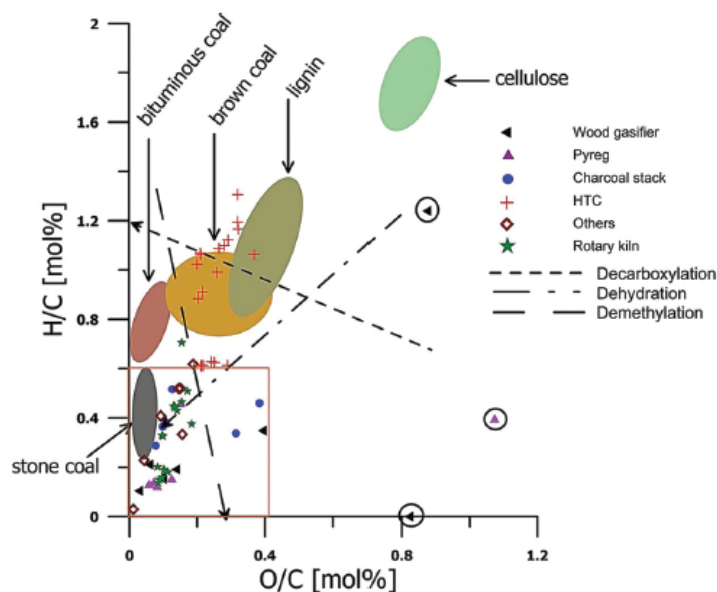


Figure B-5. Van Krevelen diagram. Source: Schimmelpfennig and Glaser (2012)

The use of the molar H/C_{org} ratio is proposed instead of the H/C ratio, as the former does not include inorganic C that may be present in Biochar, mostly in the form of carbonates (e.g. calcite and, to some extent, dolomite) (Schumacher, 2002), and is not part of the condensed aromatic structure of C and thus is not expected to remain in soil on a centennial scale.

Volatile Matter Content

The content of volatile matter (VM) in Biochar has also been observed to be inversely related to Biochar stability, calculated as mean residence time or half-life (Enders et al., 2012; Zimmerman, 2010; Spokas, 2010). Volatile matter content can be measured through different

paths, usually thermal treatment, (e.g. the ASTM method D1762-84¹⁸ (2007) (CDM SSM AMS.III-L; DeGryze et al. 2010; Enders et al., 2012)), also termed Proximate Analysis, which covers the determination of moisture, volatile matter, and ash in a variety of materials.

VM is well correlated with elemental ratios (O/C and H/C), as shown in Figure B-6 for O/C ratios. As a result, it could be expected to be a good predictor of Biochar carbon stability. However, Spokas (2010) found a weak correlation between VM content and the estimated Biochar half-life using data from 37 Biochar sample measurements from different studies (Figure B-7). Therefore volatile matter is discarded as a well-suited predictor of stability.

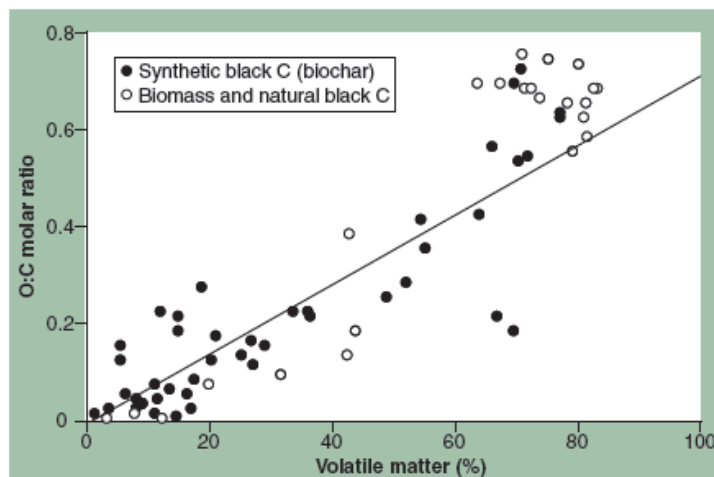


Figure B-6. Correlation of volatile matter and O/C molar ratio. Source: Spokas (2010) ($R^2 = 0.76$)

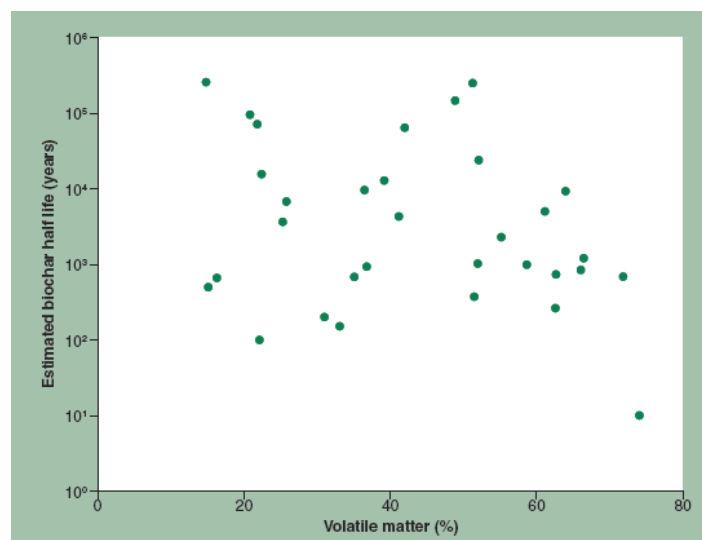


Figure B-7. Comparison of volatile matter content with estimated Biochar half life. Source: Spokas (2010) (R^2 not available)

¹⁸ Chemical analysis of wood charcoal

Beta methods

Beta methods are those that (1) directly quantify BC loss over a period of time, and (2) demonstrate a relationship with results of an Alpha method (a more conveniently measured parameter) and Gamma values for a range of Biochar types. At present, the Beta methods in use are laboratory and field-based incubations as well as field chronosequence measurements, all of which must be combined with modeling to estimate Biochar C lost over the specific time interval of 100 years (BC₋₁₀₀).

Beta methods provide an absolute measure for the carbon that will remain in Biochar for at least 100 years (at minimum, a conservative estimate of stability). Beta methods are not widely available or obtainable at a cost or within the timeframes specified for Alpha methods. It is also not feasible to have registry of direct observations of Biochar for 100 years, in order to demonstrate the suitability of a Beta method. Some Beta methods have been published and are presented below.

Incubation and Field Studies

Incubation studies of Biochar under laboratory conditions (Zimmerman, 2010; Singh et al., 2012) and studies of Biochar in soils (Major et al., 2010b; Cheng et al., 2008; Liang et al., 2008; Kuzyakov et al., 2009) have recorded temporal Biochar decomposition patterns (see Figure B-8). Observations derived from incubation experiments are critical to the understanding of Biochar behavior and, therefore, projected longevity in soils. The incubations (3-5 years of duration) were undertaken in controlled environmental conditions (e.g., moisture, temperature) and with the addition of microbial inoculations and nutrient solutions in order to promote mineralization. Because these are closed systems and non-variant conditions, estimates of stability based on these measurements can be considered conservative. Mineralization rates have been observed to decrease until reaching a constant rate at around 600-700 days, indicating that remaining Biochar carbon may exhibit a certain degree of stability. In order to quantify stability a very conservative approach must be used for extrapolating measurements from short- to medium-term studies to 100 years, which is done in this report, as explained in subsequent sections.

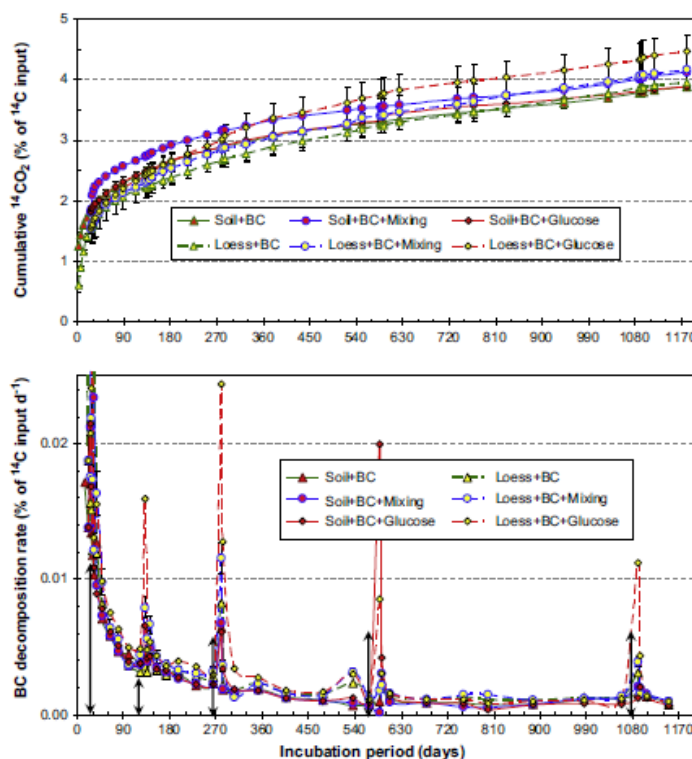


Figure B-8. Biochar mineralization rate. Source: Kuzyakov et al., 2009 (3.2 year incubation)

Both two-component (double exponential) models (e.g. Cheng et al., 2008; Zimmerman et al., 2011; Singh et al., 2012) and power regression models (e.g. Zimmerman 2010) have been used to extrapolate measurements from incubations of freshly produced and aged Biochar to predict the longer-term stability of Biochar. The second model may better represent the physical characteristics of Biochar and assumes an exponentially decreasing degradation rate, whereas the first assumes Biochar is composed of only two fractions – labile and stable. Thus, the two-component model is likely to underestimate stability of Biochar C and will yield a more conservative estimate of C sequestration, since the greater the number of pools that are added, the larger predictions of stability will be.

Chronosequences:

A Biochar C loss rate can also be determined by using measurements of Biochar distribution from sites that vary in time interval since Biochar was applied (a chronosequence). However, results of these types of studies, thus far, range from no loss to complete C loss, and are likely affected by erosion or translocation (Nguyen et al. 2008; Major et al. 2010b; Foereid et al. 2011).

Gamma methods

Gamma methods measure molecular properties relevant to Biochar stability and can verify the legitimacy of the Alpha and Beta methods through establishing strong relationships between the properties measured by them. Thus, Gamma methods would provide safeguard against selection

of Alpha or Beta methods based on empirical correlations that do not reflect a functional relationship. Some Gamma methods are briefly described below.

NMR spectroscopy (Brewer et al., 2011; McBeath et al., 2011)

Direct polarization ^{13}C nuclear magnetic resonance spectroscopy with magic angle spinning (DP/MAS ^{13}C NMR) is a well-established technique for measuring the aromaticity (fraction of total carbon that is aromatic) of Biochars. Aromaticity is strongly correlated to C stability (Singh et al., 2012) and aromaticity can be predicted by the H/C_{org} values of Biochar (Wang et al., 2013). The ^{13}C NMR spectrum of aryl carbon (i.e. derived from condensed aromatic carbon) is very characteristic, comprising a single resonance centered at approximately 130 ppm. Spinning side bands associated with the presence of aromatic carbon can be detected.

Pyrolysis Gas Chromatography mass spectrometry (Py GC/MS) – analytical Pyrolysis (Kaal et al., 2008, 2009, 2012; Fabbri et al., 2012)

Analytical Pyrolysis is a technique that uses controlled invasive thermal degradation to break down large molecules for identification. The resultant Pyrolysis products are separated and identified using gas chromatography and mass spectroscopy. The sum of the most abundant fingerprints of charred material in pyrograms (i.e., monoaromatic hydrocarbons, polyaromatic hydrocarbons, benzonitriles/total quantified peak area) is related to the proportion of condensed aromatic carbon present in Biochar.

Ring Current NMR (McBeath and Smernik, 2009; McBeath et al., 2011)

This method gauges the degree of aromatic condensation of Biochars. It involves sorbing ^{13}C -labeled benzene to the Biochar structure. The ^{13}C NMR chemical shift of the sorbed benzene (relative to straight ^{13}C -benzene) is affected by diamagnetic ring currents that are induced in the conjugated aromatic structures when the Biochar is placed in a magnetic field. These ring currents increase in magnitude with the increasing extent of aromatic condensation.

Benzene polycarboxylic acids (BPCA) (Glaser et al., 1998; Brodowski et al., 2005; Schneider et al., 2010)

The BPCA are molecules formed during the nitric acid oxidation of Biochar. The maximum number of carboxylic groups reflects the number of quaternary C atoms initially present. Biochar with a higher degree of condensation should result in higher proportion of the penta (B5CA) and hexacarboxylic (B6CA) benzoic acids relative to BPCAs with less quaternary carbon atoms (B3CA, B4CA). The ratio of B6CA-C/total BPCA-C thus is positively related to the degree of condensed aromatic C present in Biochar; the larger the ratio the greater the aromaticity. The concentration of the sum of BPCA can be used to quantify Biochar in the environment, e.g. in soil amended with pure Biochar or in mixture with other organic materials.

Gamma methods are not expected to be used by Biochar producers for determining Biochar C stability. This is mainly because of the high level of technical expertise required to perform these tests, specialized expensive instruments, high costs per analysis, and low availability. Instead, Gamma methods are intended to be used by scientists in order to calibrate Alpha and Beta methods for iterative improvement of a simple Biochar C stability test method.

Material and methods: Biochar Carbon Stability Test Method selection process

Twenty-eight test methodologies currently used to assess Biochar characteristics, mostly related to stability, were reviewed and evaluated by the Expert Panel. H/C_{org} was selected as the preferred Alpha method for being cost-effective, simple, replicable, and published in peer-reviewed literature. Modeled data from observations of carbon degradation from 3- to 5-year incubation studies (Zimmerman, 2010 as extended in Zimmerman and Gao, 2013; and Singh et al., 2012) was used as the Beta method to calibrate the predictions and determine BC_{+100} .

Results

A strong relationship was found between the H/C_{org} values of 31 Biochar samples from the two mentioned studies and the predicted BC_{+100} values, based on the two-component model (Figure A2-9).

The observed behavior for carbon in each of the 31 samples followed a typical pattern as shown in Figure B-8, where after some months, the turnover rate slowed, and exhibiting little carbon loss. The two Q10 adjustments for harmonizing the data between both studies were not made. However, even if a low value were to be used, e.g. $Q10 = 2$ (compared to Cheng et al., 2008), harmonizing the data from 30°C that lack soil minerals (Zimmerman, 2010) to 22°C (Singh et al., 2012), would yield higher BC_{+100} values than the ones reported in this Methodology, thus complying with the conservativeness principle. In addition, it is conservative to utilize the data with high incubation temperatures of 30°C and 22°C, given that the global mean temperature is less than 10°C (Rohde et al., 2013). With even a low Q10 of 2, a recaluculation of only 22°C to 10°C would make a large change to BC_{+100} . Grouping the predicted BC_{+100} values, based on the two-component model, results in Figure B-9.

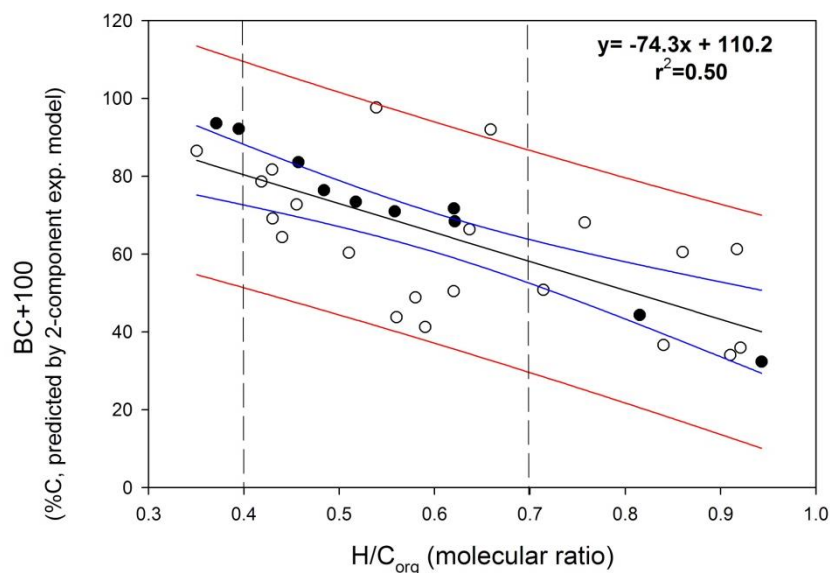


Figure B-9. The correlation between H/C_{org} and Biochar C predicted to remain after 100 years as predicted by a two-component model (i.e. BC_{+100}) was produced using data and calculations from Singh et al., 2012 (closed circles) and Zimmerman, 2010 as extended in Zimmerman and Gao, 2013 (open circles).

The vertical axis in Figure B-9 represents the percentage of organic carbon present in Biochar that is expected to remain in soil after 100 years. Thus, a Biochar sample with a H/C_{org} value of 0.6 would be predicted to have a BC_{+100} of 65.6%, indicating that 65.6% of the organic carbon measured in Biochar will likely remain in soil for at least a century. The statistical basis for this inference is presented below.

The blue and red lines in the plot represent the 95% confidence upper and lower intervals, and the 95% prediction intervals, respectively. The correlation measure shows a modest value ($R^2 = 0.5$). As Biochar is composed of various constituents, it is notable that this one parameter (H/C_{org}) explains 50% of the variation in the carbon stability of the Biochar samples assessed. Furthermore, every individual sample but one falls within the 95% prediction interval, which predicts the range in which values of future samples will fall. Additionally, a p-value below 0.0001 indicates the strong statistical significance of the calculations. Thus, this regression model is judged adequate for determining BC_{+100} based on H/C_{org} measurements.

Defining cut-offs every 0.1 for H/C_{org} values in the range of 0.4 to 0.7 for the Biochar samples, the equivalent mean, upper limit and lower limit BC_{+100} values are obtained for analysis (Table B-2). Two distinct levels can be evidenced: for an H/C_{org} value of 0.4, the lower limit of the confidence interval of BC_{+100} is above 70% (in a range of 88-72%). From this it is concluded that at least 70% of the C_{org} measured in Biochar is predicted to remain in soil for 100 years with 95% confidence, for an H/C_{org} value lower or equal to 0.4. Confidence intervals are considered over prediction intervals, as they exhibit the probability that they will contain the true predicted parameter value, for the selected confidence level.

On the other hand, for an H/C_{org} value of 0.7, a BC_{+100} of 50% can be conservatively expected. If a cut-off of BC_{+100} is defined at 50%, most (17 out of 19) of the observed values in the 0.4-0.7 H/C_{org} range would fall above this point, therefore underestimating stability. Thus, cut-offs at values of H/C_{org} of 0.4 and 0.7 are defined to characterize “highly stable” (BC_{+100} of 70%) and “stable” (BC_{+100} of 50%) C_{org} in Biochars, respectively.

Table B-2. H/C_{org} and BC_{+100} equivalences at 95% confidence

H/C_{org}	BC_{+100} (%)			
	Mean	Lower Limit	Upper Limit	Chosen Value
0.4	80.5	72.6	88.2	70
0.5	73.1	67.1	78.9	50
0.6	65.6	60.5	70.6	50
0.7	58.2	52.5	63.8	50

Biochar materials that obtain H/C_{org} values higher than 0.7 are not considered to be Biochar, as these materials would not meet the definition of Biochar as defined by the IBI Standards.

Discussion

The comments in this section seek to provide guidance as to the possible next steps for the continuous improvement of the predictability of different Alpha, Beta and Gamma methods.

The members of the Expert Panel agreed upon the necessity of continued collaboration to further refine the proposed method. Interest emerged to start the exchange of Biochar samples to run different laboratory tests in the form of a ring trial. Additional funding would be needed for this very desirable initiative to occur. As stated earlier in this document, as new findings emerge, they should be incorporated into the proposed Methodology, with the aim of obtaining the most precise and, at the same time, the most economically feasible method for determining BC_{+100} .

Fate of Biochar

Biochar transport mechanisms

The physical movement of Biochar away from the point of soil application appears to occur at a similar rate to or possibly faster than for other organic carbon in soil (Rumpel et al., 2005; Guggenberger et al., 2008; Major et al., 2010b). Eroded Biochar C is considered to remain sequestered as it is typically buried in lower horizons of soil or in lake or ocean sediments (France-Lanord and Derry, 1997; Galy et al., 2007; Van Oost et al., 2007).

Biochar can move from the topsoil into the subsoil i.e. translocation (Major et al., 2010b). It is not clear whether this transport occurs at the same rate as other organic matter in soil (Leifeld, 2007). It may be assumed that different pathways operate for particulate Biochars in comparison to dissolved organic C (Zhang et al., 2010). Biochar in subsoils can be considered stabilized to a greater degree than Biochar in topsoils, as evidenced by the great age of organic carbon found in

subsoils in general, and because microbial activity sharply decreases with depth (Rumpel and Koegel-Knabner, 2011).

Some studies indicate that a significant fraction of land-applied Biochar can be exported within the first few years following amendment, even when Biochar is incorporated into soil (Rumpel et al., 2009; Major et al., 2010b). However, physical transport of Biochar offsite does not necessarily result in a CO₂ flux to the atmosphere, as the final fate of charcoal erosion from the land surface may be deposition in marine sediments. The intrinsic refractivity of charcoal in marine environments may lead to its long-term storage in sediments (Masiello, 2004). It is reasonable to assume that mobilized Biochar does not decompose, and remains a long-term carbon sink as it transits to the sea floor.

There is a small risk of losing C to the atmosphere from Biochar which has been exported through the mobilization of Biochar C into pyrogenic dissolved organic C (DOC). But studies show that this mechanism only accounts for the movement of a small fraction of the total carbon in Biochar. Over 2 years after field application, 1% of Biochar applied to an Oxisol was mobilized by percolating water, mostly in the form of DOC rather than particulate organic C (Major et al., 2010b). In a study simulating the geochemical weathering of Biochar, only 0.8% of the total organic C was released as DOC (Yao et al., 2010). And a maximum of 1.3% of the C was extracted from any of the Biochars tested using multiple sequential leaching experiments (Zimmerman and Gao, 2013). Because soluble C may represent the same portion of C that is mineralizable C (Leinweber, 1995; Zimmerman and Gao, 2013), the additional mineralization of Biochar C via DOC is assumed to be minor, even when translocation occurs. While further research pertaining to C mineralization of dissolved Biochar is crucial, existing field and laboratory experiments show the loss of C to the atmosphere due to mobilized Biochar DOC mineralization to be minor.

Combustion

Biochar can be combusted, either unintentionally due to inappropriate handling during transport, storage or application, or intentionally, by diverting it from the intended land application to a use as fuel, since many Biochars can possess a significant energy value. Through Applicability Condition 4, the methodology assures that Biochar used only as a soil amendment qualifies therefore mitigating the risk that the Biochar will be combusted. Another theoretical oxidation by combustion is through vegetation fires. Re-burning of previously deposited pyrogenic carbon from vegetation fires has been observed in Mediterranean forests (Knicker et al., 2006). It is unlikely that vegetation fires will lead to a significant re-burning of applied Biochar that is incorporated into the soil. Temperatures during fires decrease dramatically with soil depth, and mixtures of Biochar and soil will exhibit no greater combustibility than that of other organic matter in soil.

Resolution of information on carbon stability

Although there is a clear correlation between the H/C_{org} ratios and BC₊₁₀₀ over a wide range of values at a 95% confidence level (Figure B-9), variability will remain in the stability predictions. Future refinement and a greater data set with longer-term incubation experiments, including field

data, will allow better constraint of the relationship. For the purpose of this first Methodology, as mentioned previously, a very conservative approach was chosen (e.g. via the selection of the model to obtain BC_{+100} and the conditions of the incubation experiments) and thus predictability can be further improved over time.

The second analytical constraint stems from the quantification of inorganic and organic C (and H) in the Biochar (Wang et al., 2013). Some uncertainties in the Standard method using acidification and repeated determination of total C led to an initial recommendation of restricting the Methodology to class 1 Biochars (as defined in the *IBI Biochar Standards* under the criteria for Organic Carbon in Table 1). For these Biochars, which by definition contain more than 60% organic carbon, the proportion of inorganic carbon is likely negligible and organic carbon is roughly equivalent to total carbon. However, data analysis determined that this restriction yielded no change in the prediction results. Nevertheless, a method for calculating inorganic carbon in the sample was included, allowing the calculation of organic carbon by difference to total carbon. This exemplifies how the conservative approach mentioned was operationalized in the decisions made to arrive at a test method.

Future improvements to Alpha, Beta and Gamma methods

Alpha

The choice amongst routine analytical procedures that would reflect a robust, repeatable, and analytically sound result was limited to those that had been used in the peer-reviewed literature. These included the Standard Test Method for Chemical Analysis of Wood Charcoal, so-called Proximate Analysis (ASTM-D1762-84, 2007) and elemental ratios of O, H and C. Structural information beyond stoichiometric relationships between elements may provide better estimates of stability and may be attainable through spectroscopy or automated thermogravimetry. However, these have not been sufficiently developed or are not available at a sufficiently low cost or time requirement to be included at present, or both.

Beta

Longer periods of observation will likely provide evidence to improve precision of predictions of BC_{+100} (Lehmann et al., 2009; Zimmerman et al., 2012), likely increasing the stable carbon component calculated, since the current proposed method is highly conservative. The known long-term incubations experiments will continue and a revised future Methodology will reflect improvements based on longer periods of observation. Only a few long-term field experiments have been published beyond a few years (Major et al., 2010), but are expected to be available for up to 10 year-periods in the coming years. However, pitfalls of field experiments are that these often do not distinguish between mineralization and physical loss by erosion and leaching, and the capabilities to estimate these differential losses over long periods of time are typically low. Therefore, these experiments often give, at best, a minimum mean residence time. A third approach is the use of aged Biochars as proxies for Biochar that has weathered in soil for long periods of time. Examples are Biochar-type materials from Terra Preta (Liang et al., 2008), from charcoal storage sites (Cheng et al., 2010) or possibly archaeological deposits. The challenge using this approach is to develop adequate proxies for the starting material to assess its properties.

Gamma

Great progress has been made over the past years in understanding the change in the chemical form of fused aromatic carbons beyond aromaticity. Advancement in this area may come from NMR studies (Mao et al., 2012), measurements of adsorbed C-13-benzene (McBeath et al., 2012) and wet chemical methods such as BPCA (Glaser et al., 1998; Brodowski et al., 2005; Schneider et al., 2010). To improve predictability of Biochar decomposition, next steps may include systematically relating structural information to improved Alpha-type methods, as defined in this document

Conclusions

One of the most important properties of Biochar – if not the most important one – is its stability, as it allows all other ancillary environmental benefits, especially as they pertain to agronomic properties (i.e., soil amelioration and enhancement), to persist in time. Mainly, the stability of the carbon component in Biochar makes it particularly useful as a long-term climate change mitigation strategy, and thus having a scientifically valid Methodology for the quantification of stable carbon will allow unlocking the potential benefits of Biochar. That is what makes this effort, oriented by an Expert Panel, ground-breaking, and as such can contribute to the development of policies and programs that promote the deployment of Biochar systems.

Given that this is the first such Methodology to be developed, and that the science is rapidly evolving, the Panel necessarily devised a conservative Methodology that is likely to underestimate the amount of stable carbon in Biochar to a period of 100 years. But with continued research and development, some of which is described herein, we are confident that the test Methodology will grow more robust and more rigorous over time, allowing for a more complete and precise estimation of stable carbon in Biochar.

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